STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY,
MATERIALS AND RESEARCH

VEHICLE CRASH TESTS OF A CONCRETE MEDIAN BARRIER RETROFFITTED WITH A CONCRETE GLARE SCREEN

Final Report # FHWA/CA/TL-92/05

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THIS STUDY WAS CONDUCTED IN COOPERATION WITH THE U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION.

16. ABSTRACT

Two vehicle crash tests were performed on a retrofit concrete glare screen slipformed on top of an existing 32-inch high concrete safety shape barrier. The concrete glare screen is intended as a replacement for the current standard expanded metal mesh glare screen. This concrete glare screen is 20-inches high, 6-inches thick at the base and tapers slightly to 5-inches thick at the top. Reinforcing consists of two longitudinal #4 bars tied to vertical #5 hoops (inverted U-shaped stirrups.) At the base of the glare screen is a 3/4-inch chamfer to match that at the top of the concrete barrier.

The two test vehicles included a pickup truck ballasted to 5390 lbs. travelling 55.3 mph and impacting at 20 degrees; and a large car ballasted to 4360 lbs, travelling 56.2 mph and impacting at 25 degrees.

Both tests showed that a concrete glare screen can successfully withstand the impact of both a pickup truck and a heavy passenger car, and satisfy the requirements for structural adequacy, occupant risk and vehicle trajectory in NCHRP Report 230.

Maintenance costs for the concrete glare sceen should be less than those for the metal mesh glare screen.

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SI CONVERSION FACTORS

To Convert From	To	Multiply By
	ACCELERATION	
ft/s^2	m/s^2	0.3048
	AREA	
ft^2	m^2	0.0929
	ENERGY	
ft.lbf	Joule (J)	1.3558
	FORCE	
lbf	Newton (N)	4.4482
	LENGTH	
ft	m	0.3048
in	m	0.0254
in	cm	2.5400
	MASS	
lb	kg	0.4536
	PRESSURE OR STRESS	
psi	Pascal (Pa)	6894.76
	VELOCITY	
mph	km/h	1.6093
ft/s	m/s	0.3048

ACKNOWLEDGEMENTS

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Ralph Bishop and Jon Hamaguchi, Division of Structures, technical consultation; Don Tateishi and Herb Holman, Headquarters Photo Section, crash test photography.

Mike Baumgartner, Inc. was the contracting firm that constructed the test barrier. Mike Baumgartner, who has considerable experience slipforming concrete barriers, offered valuable suggestions on the glare screen design and arranged for the design of a new slipforming "mule" to construct the concrete glare screen.

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1.1 PROBLEM

Since the early 1970's, head light glare from opposing traffic has been of concern to traffic engineers. The standard material now used to screen glare in California is an expanded metal mesh mounted on top of concrete median barriers between opposing streams of traffic (1). This glare screen is only installed on barriers in medians that are less than 20 feet in width, to shield driver's eyes from the headlight glare of oncoming vehicles (2).

In the mid 1980's the Division of Highway Maintenance concluded that the amount of time spent maintaining expanded metal mesh was excessive and exposed maintenance personnel and the traveling public to potential traffic safety hazards (see §1.3). The glare screen in the narrow medians appeared to be easily damaged by repeated wind gusts from passing trucks, wind, vandalism, roadway debris and vehicle impacts. The Division initiated a value engineering study into how glare screen maintenance concerns could be reduced (3).

A Caltrans value engineering team determined that "maintenance forces have to repetitively devote large amounts of time repairing glare screens in specific areas". The team recommended that the expanded mesh glare screen be replaced with a reinforced concrete glare screen because of its greater strength and durability, its excellent glare protection, its low maintenance, and its added barrier protection. A concrete glare screen design needed to be crash tested to verify that it would not increase any safety concerns in an automobile crash.

1.2 OBJECTIVE

To design and crash test a retrofit concrete glare screen (CGS) slipformed on top of an existing safety shape concrete median barrier (CMB), to be qualified for use on California State highways. This design, when adopted and implemented, would replace one using expanded metal mesh glare screen mounted on top of the CMB.

1.3 BACKGROUND

The Chief of the Caltrans Division of Highway Maintenance initiated a value engineering study to improve the adequacy of the current design because of the large amounts of time maintenance forces were spending on the repair of glare screens in some areas. The study titled "Value Engineering Study of Glare Screen High-Maintenance Areas in California" (2), was presented to Caltrans management October 28, 1986.

The study team determined that the CGS would improve the expanded mesh glare screen currently in service in the following ways:

- •Better structural integrity,
- •Better resistance to wind, vehicle and pedestrian damage,
- •Less maintenance time expended, and
- •More aesthetically pleasing glare screen when broken.

The team identified at least 40 miles of barrier with glare screen that required "high" maintenance. This represents about eight percent of the glare screens now in place in California. With transportation funds dwindling and traffic increasing, the state must build highway appurtenances that have low maintenance requirements in order to:

- •Keep maintenance costs low.
- •Reduce maintenance worker exposure to traffic.
- •Reduce length of time and frequency of lane closures.
- •Reduce traffic exposure to work zones.

After studying numerous glare screen designs and materials, the study team concluded that CGS should be used in high maintenance areas. CGS was seen as having the following advantages:

- •Strong, durable and weather-resistant,
- •Common construction material easily used by contractors and maintenance personnel,
- •Less frequent need for repairs,
- •Lower life cycle cost than metal mesh over a 20 year period,
- •Excellent glare protection, dependent only on sufficient height,
- •Increased structural integrity of CMB,
- •Cuts off visibility across median, thus eliminating rubbernecking during accidents, road construction, etc.

The main disadvantages to the use of concrete appear to be:

- •Higher construction cost than metal mesh,
- •Lack of visibility across median at right angles to traffic flow which is sometimes needed for surveillance by traffic officers. The California Highway Patrol has advised us however that they support the use of the CGS.

The study team surveyed several state's glare screen standards. Nine states were switching from metal mesh to concrete. No maintenance problems were reported.

Following the study team evaluation, the Divisions of Highway Maintenance, Traffic Operations and Structures requested that a CGS be designed and crash tested for early implementation in California. A glare screen height of 52 inches was recommended by Traffic Operations. Two glare screen designs were produced for potential testing.

1. Type 50R. Retrofitted glare screen slipformed on top of existing 32-inch high Concrete Barrier (Type 50) (California New Jersey profile CMB) for an overall barrier/glare screen height of 52 inches. (Figure 1)

2. Type 55 GS (Figure 2) Full-height concrete barrier and glare screen slipformed in one operation with a 52-inch height. The slope at the base of the barrier conforms to a configuration F. The width of the base is 24 inches and the barrier is substantially reinforced. NCHRP Synthesis of Highways Practice 66, "Glare Screen Guidelines", December 1979 (2), recommends a minimum glare screen height of 50 inches and states that crash tests are warranted on concrete barrier/glare screens over 32 inches tall.

Since 1975 the State of Michigan, Department of State Highways and Transportation has been capping its concrete barriers with satisfactory results according to Mr. C.M. Ellis, Construction Staff Engineer. The concrete cap extends above the barrier 19 inches and functions as a glare screen. The cap is slip formed or cast in place over dowels and a longitudinal #4 rebar (5).

Two concrete barrier slipform equipment companies and one barrier contractor were questioned about the feasibility of slipforming concrete glare screen. Slipforming is expected to be much less costly than cast-in-place or precast concrete designs.

1.4 LITERATURE SEARCH

A TRIS literature search was conducted by the Division of New Technology, Materials and Research Library staff. A total of 41 references on glare screen were listed but there did not appear to be any reports on vehicle crash tests of CGS. Most reports were on expanded metal and louver type glare screens. The NCHRP Synthesis of Highway

Practice 66, "Glare Screen Guidelines" (4), was useful in checking for good glare screen geometry.

One report (5) was done on a non-vehicle impact test. In that test a CGS 19 inches tall was cast on top of a concrete safety shape barrier with 1/2"f x 15" dowels at 45 inches. The glare screen was impacted with a 2000 lb wrecking ball at unknown kinetic energy levels and unknown velocities and angles. The bumper of the concrete mixer truck was used to determine the elevation for the ball to strike the glare screen.

The Caltrans standard 32-inch (.81 m) high CMB can obstruct some glare. The use of this barrier on projects involving widening into the median often results in glare control on curves because of the differences in elevation which requires taller barriers. Some other states have extended the height of the standard median barrier; New Jersey has used a height of 42 inches (1.07 m), by adding 10 inches (0.25 m) above the standard median barrier. Michigan adopted a height of 52 inches (1.3 m) by adding 20 inches (0.51 m) to the standard barrier.

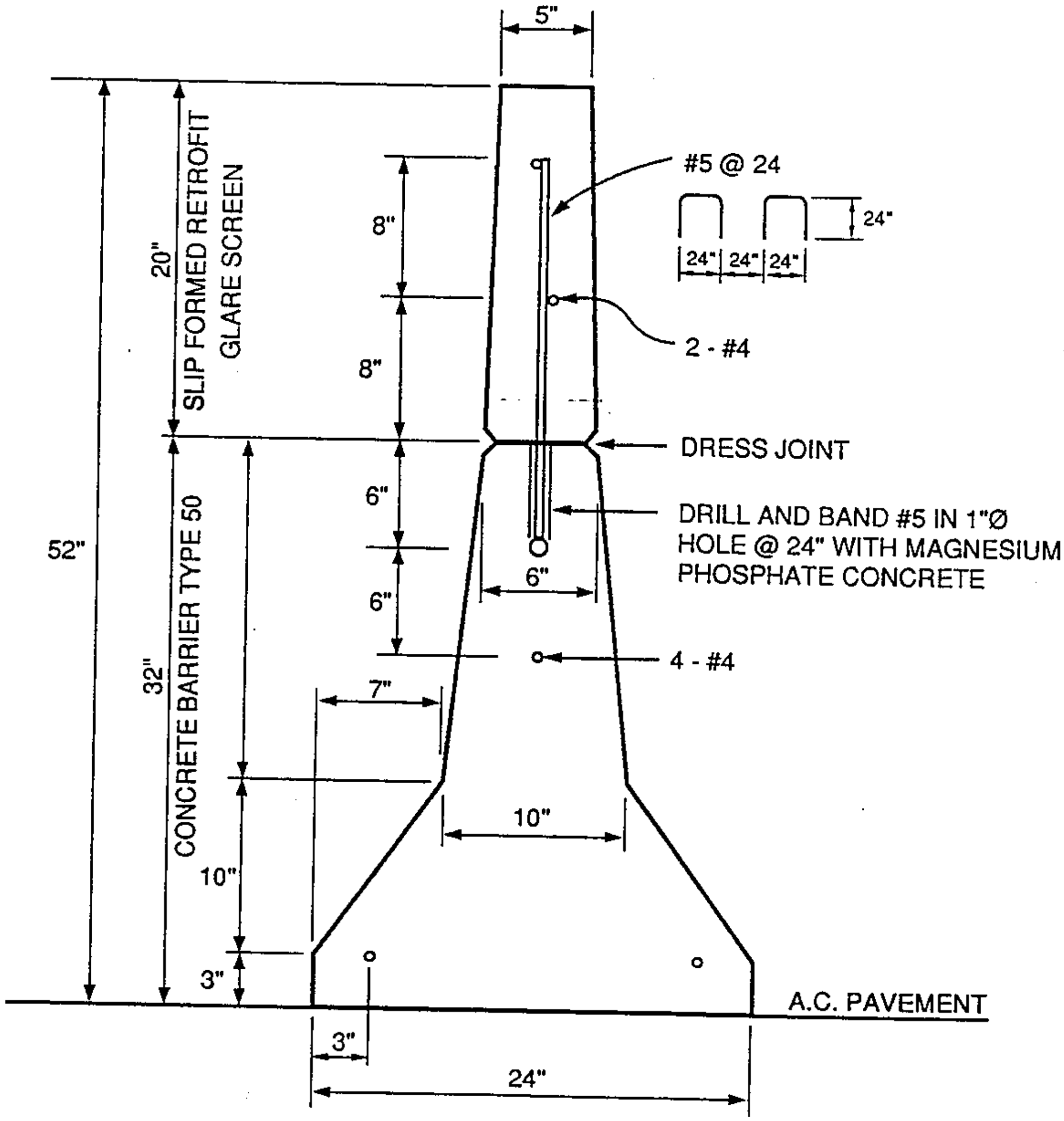


Figure 1: Typical CGS (Type 50R) Cross Section

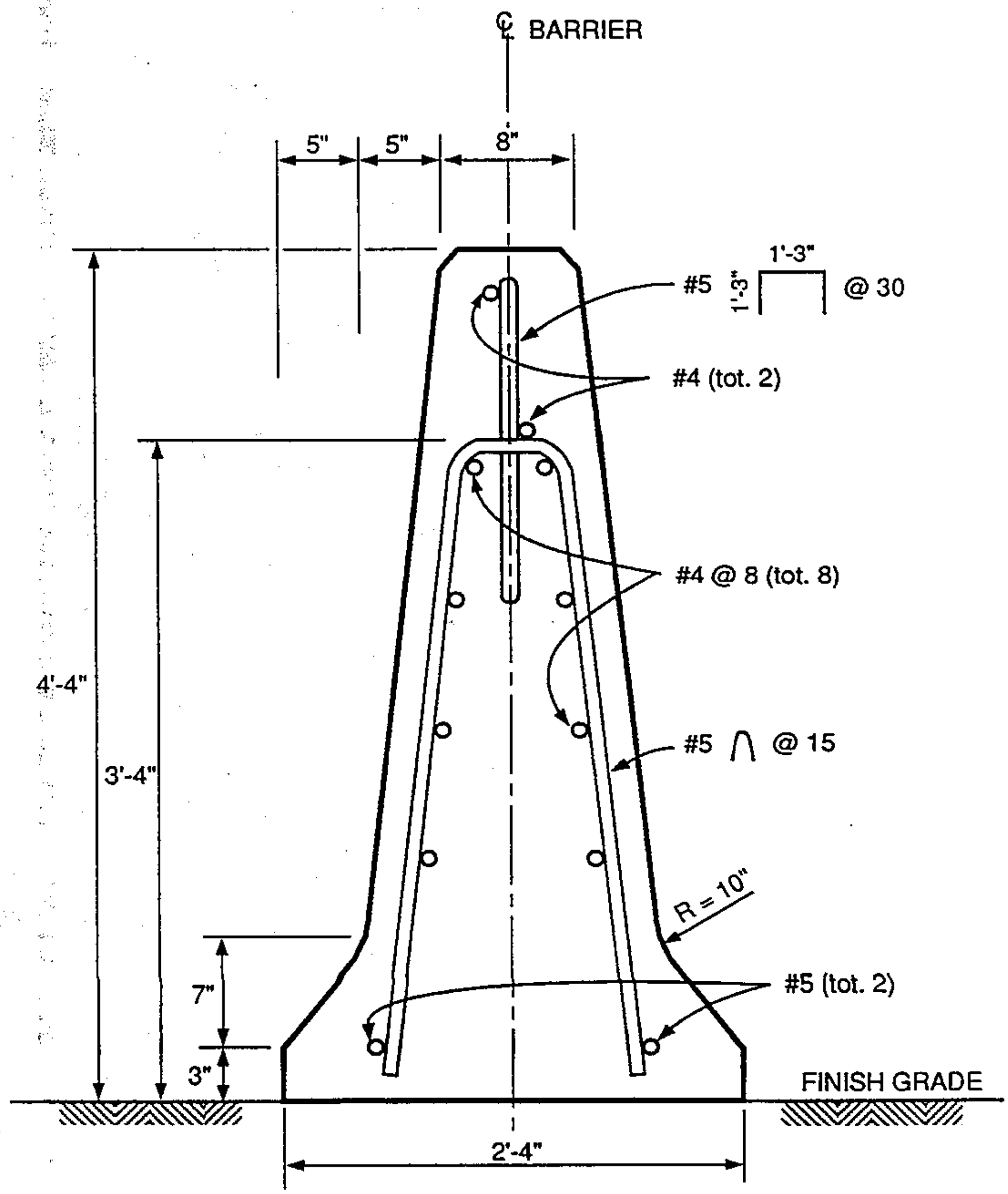


Figure 2: Typical CGS (Type 50GS) Cross Section

Based on the results of two vehicle crash tests on a CMB with a slipformed CGS the following conclusions can be drawn:

1. The barrier as tested, is structurally adequate to meet our present standards as specified in NCHRP 230 (6) including both the strength and stability requirements.

2. Large passenger vehicles can be smoothly redirected by the barrier with satisfactory occupant risk factors, per NCHRP Report 230 (6).

3. The CGS has the structural integrity, to fully contain an impact of a 5400 lb. (2449 kg) vehicle at 60 mph (26.8 m/s) 20 degrees with no evidence of structural distress or debris generation (including debris from vehicle).

4. In both tests, the exit speeds and angles of the vehicles met NCHRP Report 230 (6) requirements. The vehicle post impact trajectory resulted in a smooth redirection of the vehicle back toward the concrete barrier.

5. The two impact tests showed that the slip-form construction of concrete glare screen to a total height of 52 inches is feasible and that the completed product has considerable structural strength. There is need for tight control of the slump of the concrete mix with existing construction equipment. The CMB/CGS should provide long life and low maintenance usually associated with structural concrete.

6. Some safety enhancements may result from the additional height and strength of the CGS. For example, depending on the speed, weight and angle, an errant vehicle might be somewhat less likely to climb over a CGS equipped barrier.

7. There is zero penetration of vehicle parts beyond the face of the CMB/CGS structure.

1. If adopted, and subject to field review and study, the CGS is recommended for use with CMB in locations where review and study indicate that installation of CMB/CGS might be useful.

2. Attention should be given in the slip-form operation to the required amount of concrete slump.

3. In future installations, eliminate the use of #5 "hoops" and use single, straight #5 dowels on top of the barrier. This will reduce the restriction to the flow of concrete, hence, provide better concrete consolidation.

4. Eliminate the chamfer at the bottom of the glare screen. Place and finish the concrete flush with the face of the existing CMB that fills in the chamfer at the top of the CMB. This will give a wider structural section at the bottom of the glare screen and give it a "cleaner" appearance.

6. The Type 55GS concrete barrier and glare screen (52-inch high barrier slipformed in one pass) does not need to be crash tested because the geometry is almost the same as the Type 50R, which was tested, and it is stronger than the Type 50R by inspection.

The Division of Traffic Operations will be responsible for preparing and adopting standard plans and specifications with input from the Division of Structures and the Division of New Technology, Materials, and Research. The Division of New Technology Materials and Research has produced a videotape showing glare screen construction and the impact tests. The videotape can be used to familiarize Caltrans personnel and others with the new design.

5.1 TEST CONDITIONS

5.1.1 Test Facilities

The two impact tests were conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The tests were performed on a large flat asphalt concrete surface. The test barrier was placed on the pavement. There were no obstructions nearby except for a five-foot to six-foot (1.5 to 1.8 m) high earth berm about 90 feet (27.4 m) downstream from the test barrier, and a simulated bridge deck with no rail and a trench on the far side.

5.1.2 Test Barrier Design

The Type 50R barrier which was crash tested was a standard Caltrans slipformed CMB (Concrete Barrier Type 50) retrofitted with a slipformed CGS on top. The barrier design is shown in Figure 1. The barrier design was a joint effort by the researchers and personnel from the Caltrans Division of Structures. A California barrier contractor with considerable slipforming experience advised the researchers that it would probably be feasible to slipform a CGS on top of a CMB.

The CGS was lightly reinforced. Minimal reinforcement was needed to anchor the CGS to the existing CMB and to hold the CGS together if it was shattered during an impact by a passenger vehicle i.e., to prevent large chunks of concrete from flying into the opposing lanes. Nevertheless, the reinforcement could not be too congested so the concrete could be properly vibrated and consolidated during the slipform operation. The reinforcing steel was specified to conform to ASTM A615-60 specifications.

The CGS had a six inch width where it sat on top of the CMB, the same as the six-inch stem width of the CMB. The CGS tapered slightly to a five-inch top width. Minimum taper was used to get as thick a CGS as possible for added strength and ease of slipforming, but it was also thought that a slight taper was required to slipform the CGS properly. The minimum concrete strength for the test barrier was specified to be 3000 psi. It was intended that the strength not be too high so the test conditions would be conservative.

The height selected for the Type 50R barrier was 52 inches: a 32-inch CMB plus a 20-inch CGS. This is two inches higher than the minimum height recommended in the NCHRP syntheses on glare screens (4). It is also higher than the vertical center of gravity height for most vehicles. It is questionable whether a CGS this thin could be much higher and still be slipformed satisfactorily.

Scuppers were included in the test barrier design to provide the maximum weakness to the CMB that might be expected in practice.

5.1.3 Test Barrier Construction

The CMB and the CGS retrofitted to it were both constructed by the slip form method. The test barrier was 150 feet long; the minimum length is 75 feet per NCHRP Report 230 (6). The as-built plans for the barrier and the concrete glare screen are shown in Appendix D. The slipforming machinery including the new mule used to slipform the CGS is shown in Figure 3. The CMB was slipformed in one day. Slipforming was done in accordance with Section 83-2.02(3B) of the Caltrans Standard Specifications (7). Installation of the CGS on top of the CMB proceeded after the strength of the CMB concrete reached 3000 psi as determined according to California Test Method 521 (9).

Initially, there were some problems with the slipforming operation. The new mule for the CGS had never been used before. The first few feet of the CGS that were slipformed pulled apart, contained rock pockets, and seemed unstable and easily warped away from plumb. This was due to inadequate vibration during the slipform operation and also due to the low slump concrete. To counteract this, a bit of water was added to the concrete and the location of the vibrators was changed.

Considerable patching and finishing were required after the CGS was slipformed, particularly in the beginning section. Once the finishing was complete, the CGS generally appeared straight, plumb and consolidated. It is expected that the ease of slipforming and the integrity of the CGS would improve as the contractor gained experience with the new mule. Figure 4 shows the glare screen under construction, and Figure 5 shows it after hand finishing. Static strength results from concrete test specimens of the CMB and the CGS are tallied in Appendix E.

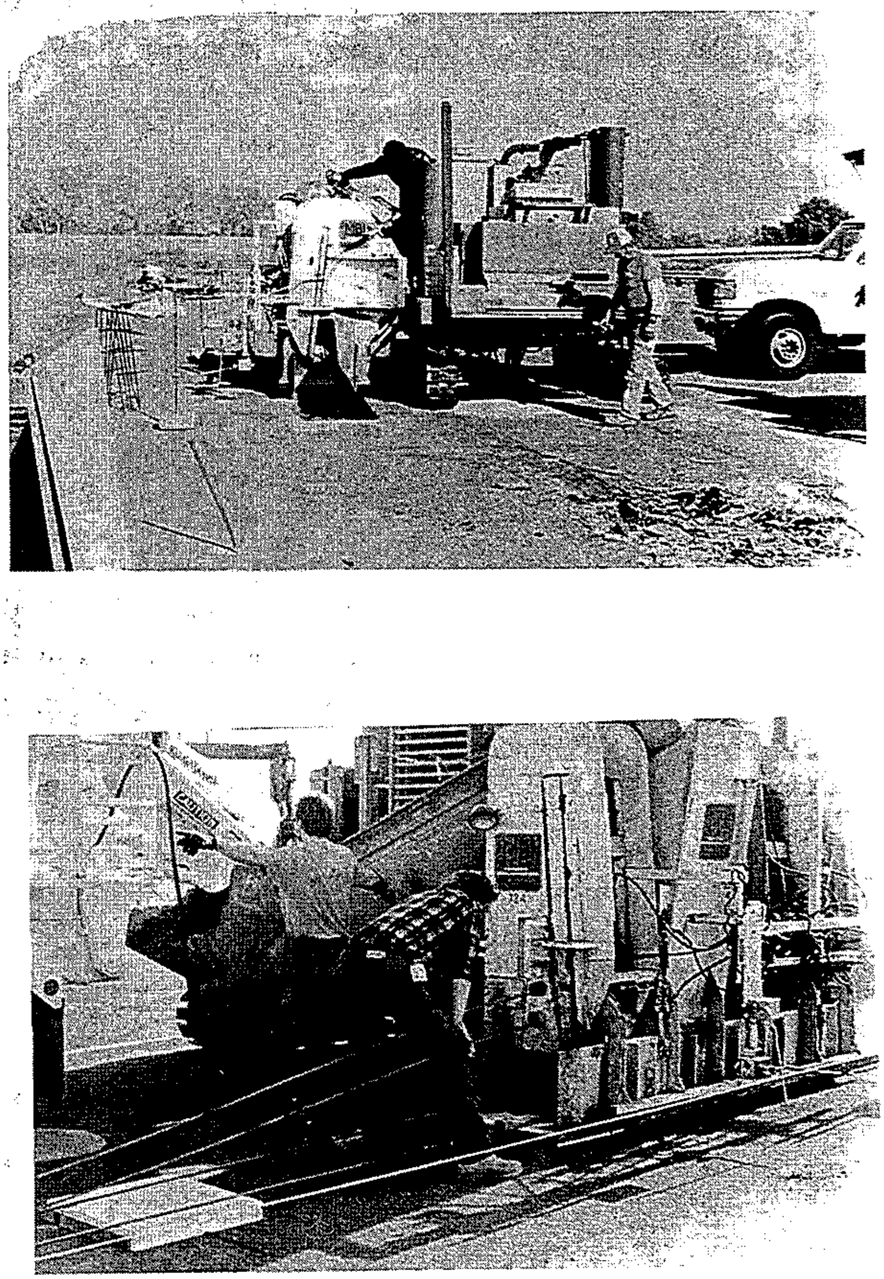
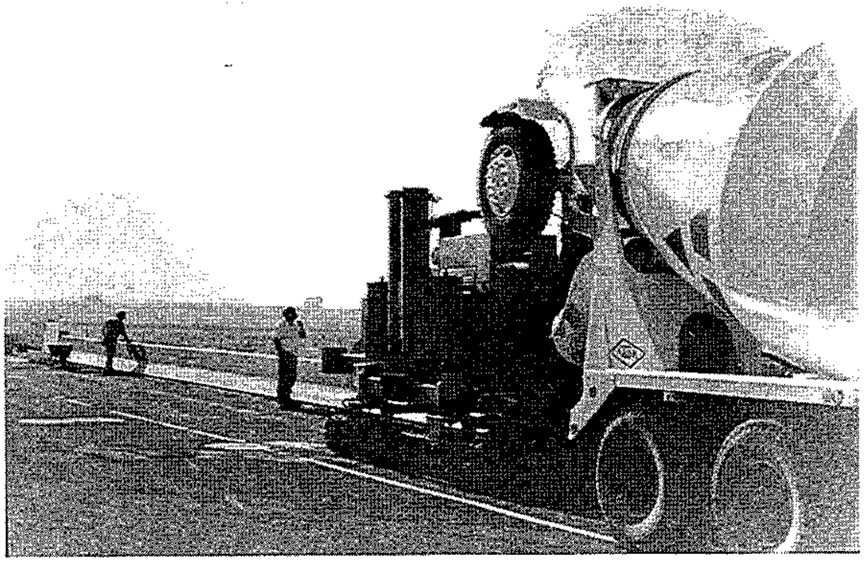


Figure 3: Slipforming Machinery Used in CGS Construction



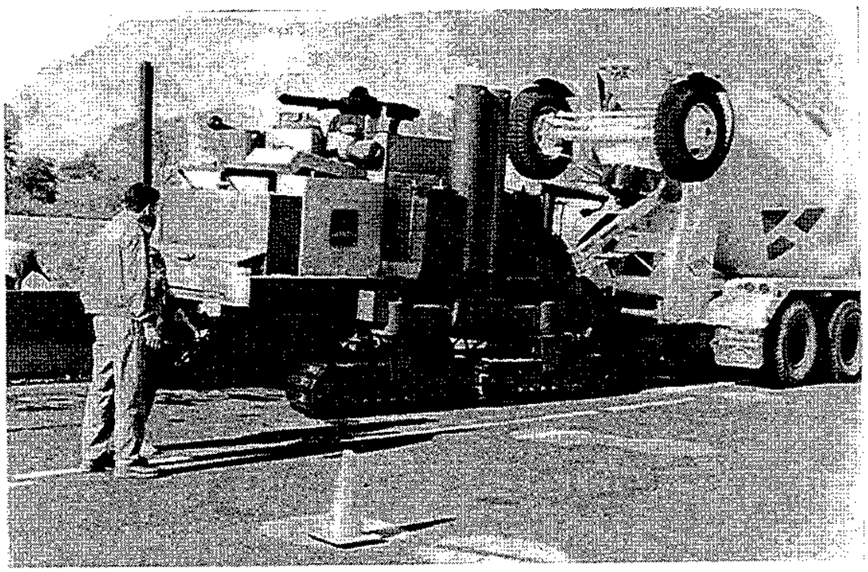


Figure 4: CGS Under Construction

Figure 5: Finished CGS

5.1.4 Test Vehicles

The test vehicles complied with NCHRP Report 230 (6). For both tests, the vehicles were in good condition and free of major body damage and missing structural parts. All equipment on the vehicles was standard. The vehicles had front mounted engines, rear wheel drive, and automatic transmissions. Fifty pound steel plates were securely mounted on both test vehicles to achieve the desired vehicle weights. The vehicle types used in the tests and the vehicle weights are shown in Table 1.

Test No.	Vehicle	Steel Plate Ballast Weight [lb (kg)]	Total Test Inertial Weight [lb (kg)]
481	1985 Chevrolet Pickup	850 (386)	5390 (2445)
482	1982 Mercury Station Wagon	300 (136)	4360 (1977)

Table 1. Test Vehicle Information
(Key Vehicle dimensions are shown in Appendix A)

The vehicles were self-powered; a speed control device maintained the desired impact speed once it was reached. Remote braking was possible after impact. Guidance of the vehicle was achieved with an anchored cable which passed through a guide bracket on the right front wheel of the vehicles. No constraints were put on the steering wheel. A short distance before the point of impact, the vehicle was released from the guidance cable and the ignition was turned off. A detailed description of the test vehicle equipment and guidance system is contained in Appendix A.

Both impacts were on the left (driver) side of the vehicle.

5.1.5 Data Acquisition Systems

The impact phase of each crash test was recorded with several high speed movie cameras, one normal speed movie camera, one black and white sequence camera and one color slide sequence camera. The test vehicles and test barrier were photographed before and after impact with a normal speed movie camera, a black and white still camera and a color slide camera. A film report of this project was assembled using edited portions of the movie coverage.

Three accelerometers were attached to the floor of the vehicle near the center of gravity to measure motion in the longitudinal, lateral and vertical directions. Rate gyro transducers were also placed at this location to measure the pitch, roll and yaw of the vehicle. The accelerometer data were used in calculating the occupant impact velocity.

A Pacific Instruments Model 5600 digital transient data recorder (TDR) was used for recording transducer data. The Model 5600 is a 32 channel portable data recorder for field applications and it was mounted in the vehicle. The TDR digitized and recorded transducer data at a sample rate of 12.5 KHz per channel. The digitized data were transferred to, and analyzed by a personal computer. The recorded and reduced data are presented in Appendix C.

Test dummies were not used in these tests.

Potentiometers were attached to the top of the CGS in the impact area. They measured the dynamic deflections of the CGS during impacts. Appendices B and C contain a detailed description of the photographic and electronic equipment, the camera layout, data collection and reduction techniques, and accelerometer records.

5.1.6 Other Tests (X-Ray, Cutout Sections)

Two tests were performed to check the integrity of the barrier and its materials. The first one was cutting a couple of typical cross-sections out to check for rebar arrangement and concrete consolidation. A circular saw was used to cut two six inch thick cross sections from the barrier. The faces of these cross-sections were smoothed out afterwards. These cross sections showed that the rebars' final position was the same as the plans. They also showed a homogeneous, well consolidated concrete mixture with no air pockets.

The second test was a radiography test performed using standard radiographic methods. The main purpose of these tests was to locate the rebar in the barrier so that the typical cross-sections could be cut out at an appropriate location along the barrier. The x-rays were also used to check for air pockets in the concrete and to check whether there was any considerable movement in the rebar during the slipform operation. In addition, they were used to check for uniform concrete density along the barrier and also to see whether the concrete was intimately in contact with the rebars. A secondary purpose of these tests was to check for cracks in the concrete.

5.2 TEST RESULTS

The records of accelerometer data are contained in Appendix C and a film report showing the crash tests is available for viewing.

5.2.1 Test 481 [5390 lb (2445 kg)/55.3 mph (89 km/h)/20∞]

The planned test conditions were 5400 lbs (2450 kg)/60 mph (97 km/h)/20°. The Data Summary Sheet and photos taken before and after impact are shown in Figures 6 through 8.

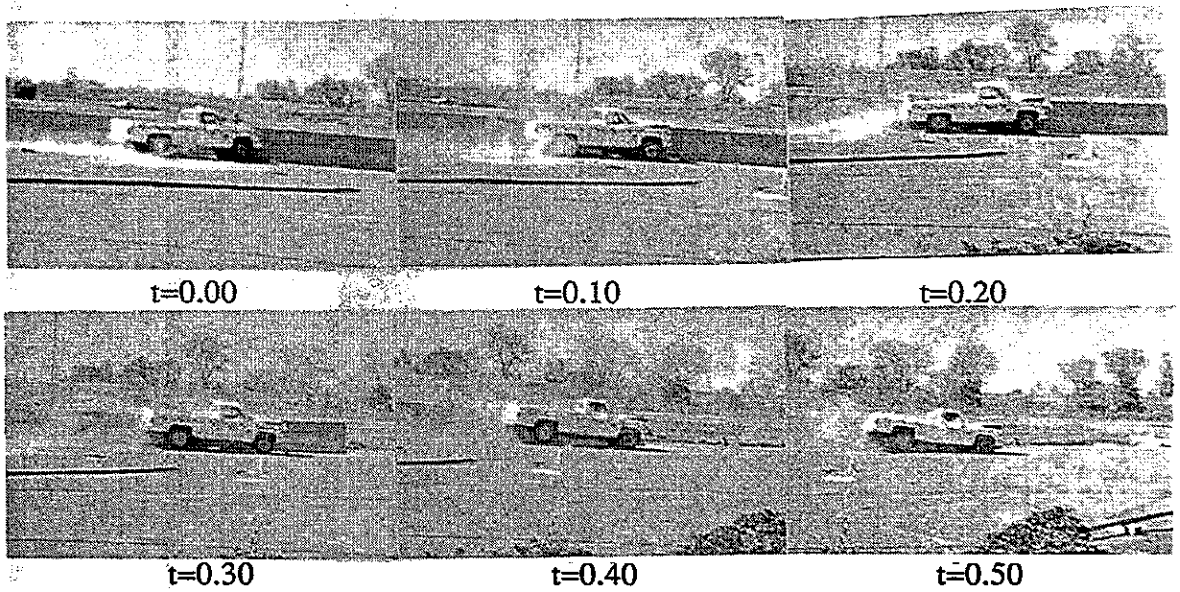
5.2.1.1 Impact Description - 481

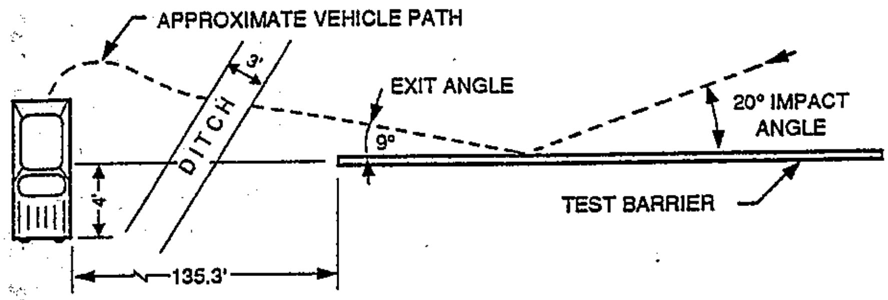
The left front tire of the vehicle made first contact with the face of the barrier 108 feet (32.9 m) from the upstream end of the barrier. The vehicle impact speed was 55.3 mph (89 km/h) and the impact angle was 20°. The vehicle rose about 2.75 feet (0.8 m) above the ground as evidenced by the marks on the barrier. The left front corner of the vehicle remained in contact with the barrier for a distance of about 17.2 feet (5.2 m).

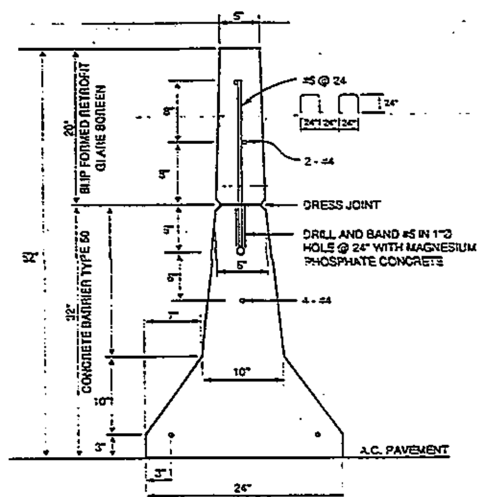
The left rear tire touched the lower part of the barrier 111.5 feet (34.0 m) from the upstream end of the barrier. The highest mark of the left rear tire on the barrier was 37 inches (0.94 m). The length of vehicle contact with the barrier was about 18.3 feet (5.6 m). The body contact of the vehicle with the concrete glare screen began 80.5 feet (24.5 m) from the upstream end of the barrier for a length of about 11 feet (3.3 m).

The pickup truck was smoothly redirected and lost contact with the barrier at an exit angle of 6 degrees without exhibiting any tendency to snag or pocket. During barrier impact, the truck experienced a maximum roll of 13.1 degrees and a pitch of -9.4 degrees. The vehicle remained upright throughout and after collision. The exit speed was 45.7 mph (73.6 km/h). Exit velocity and angle were measured at the time after impact when the vehicle first lost contact with the barrier.

Figure 6: Data Summary Sheet for Test 481







Test Barrier:

Type:	50R Concrete Glare Screen Slipformed on top of California Concrete Median Barrier - Type 50
Length:	150 feet

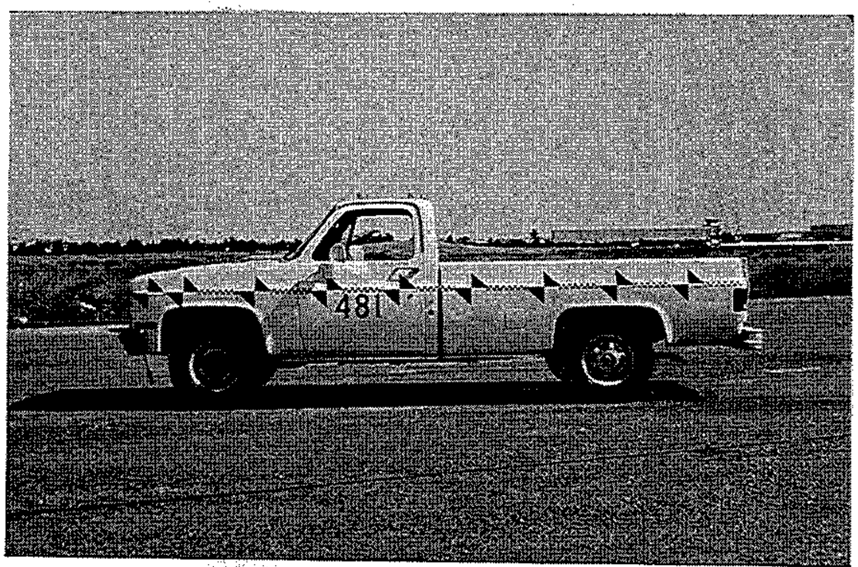
Test Date: 3/28/90

Test Vehicle:

Model:	1985 Chevrolet Pick-up Truck
Inertial Mass:	5390 lb
Impact Velocity:	55.3 mph
Impact/Exit Angle:	20°/9°

Test Data:

Occupant Impact Velocity:	9.9 fps long. / 20.6 fps lat.
Ridedown Acceleration:	1.4 g's long. / -20.7 g's lat.
Max. 50 ms Avg. Accel.:	-4.6 g's long. / -11.3 g's lat.
TAD/VDI:	11LFMW5/LFQ-4
Max. Roll, Pitch & Yaw:	13.1°/-9.4°/0°
Barrier Displacement:	0 inch
Max. Dynamic Deflection:	0.39 inch
Barrier Damage:	Few scrapes and tire marks



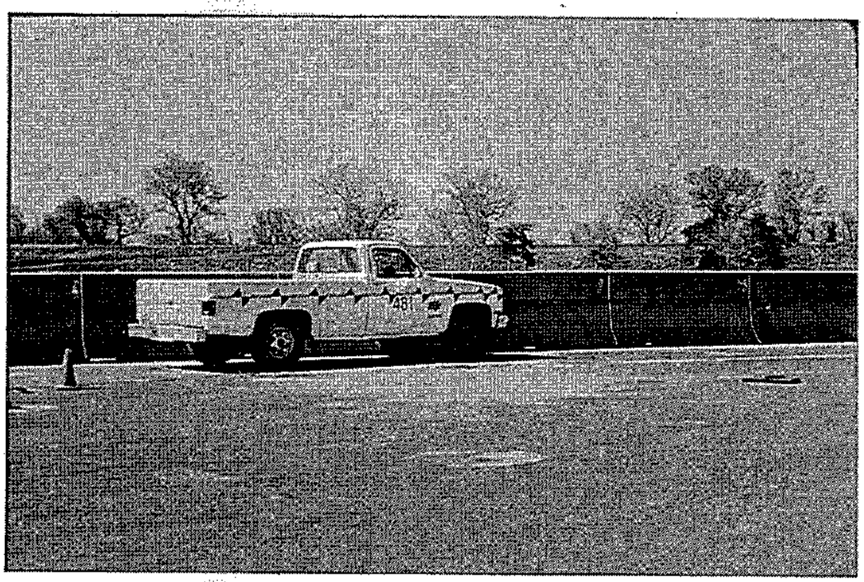


Figure 7: Pre-Impact Photos, Test 481

Figure 8: Post-Impact Photos, Test 481

The remote brakes were applied after the vehicle lost contact with the barrier and the vehicle went off the paved area. It rested perpendicularly at 135.3 feet (41.3 m) downstream from the downstream end of the test barrier. The maximum 50 millisecond average accelerations were -11.3 g's in the lateral direction and -4.6 g's in the longitudinal direction. The values of occupant impact velocity were 20.6 fps (6.3 m/s) in the lateral direction and 9.9 fps (3.0 m/s) in the longitudinal direction. The ridedown accelerations were -20.7 g's laterally and 1.4 g's longitudinally.

5.2.1.2 Vehicle Damage - 481

The test vehicle was severely damaged with crushing of left side body sheet metal. The contact pattern was initiated at the left corner of the front bumper which was crushed and bent during the impact. The grill frame was crushed at its left side and dented at its right. The grill fell out of the grill frame. The radiator was pushed back to the fan. The hood was closed and could not be opened. The left door was scraped, jammed and could not be opened. The left mirror was broken and its frame was bent inward. The left side of the pickup truck bed was severely scraped and crinkled. The truck bed was twisted causing two inch differences between the cab and the bed on the truck's left side. On the right hand side of the vehicle, the front fender was crinkled, the brake light was pushed up and broken, and the right door was jammed. All tires were flat and torn except the right front tire. The rim of the left front wheel was bent and the tire came off of the right rear wheel due to snagging on the guidance bracket. There was no intrusion of vehicle or barrier parts into the passenger compartment during impact.

5.2.1.3 Barrier Damage - 481

There was no evidence of any structural distress of the CGS or CMB. A few hair like cracks were observed but were indistinguishable from cracks due to shrinkage. They may have preexisted the crash. Lateral movement of the CGS was measured during the test; dynamic deflection was up to 0.39 inches (0.01 m) at the top face, but there was no permanent deflection.

The only damage to the barrier was a few scrapes and tire marks. The length of gouge marks on the CGS was 11 ft (3.3 m) and about 12 ft (3.6 m) on the CMB.

The tire marks of the left front wheel scuffed a length of 5.2 feet (1.6 m) on the CMB. The left rear tire marks were 11.4 feet (3.5 m) long on the CMB and 2.5 feet (0.76 m) on the CGS.

5.2.2 Test 482 [4360 lb (1977 kg)/56.2 mph (90.4 km/h)/25°]

The planned test conditions were 4500 lbs (2041 kg)/60 mph (97 km/h)/25°. The Data Summary Sheet and photos taken before and after impact are shown in Figures 9 through 11.

5.2.2.1 Impact Description - 482

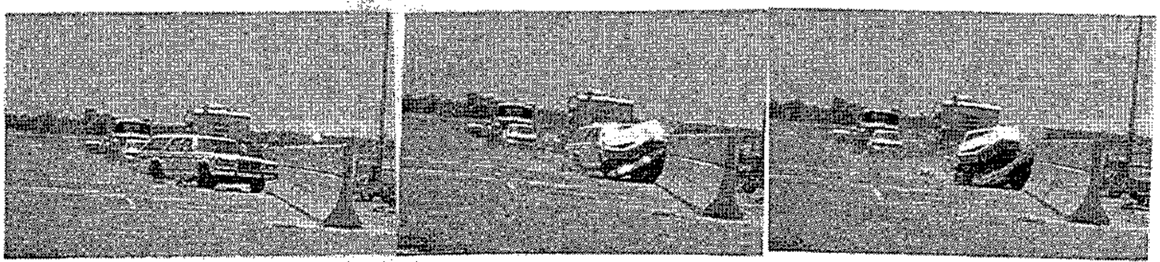
The left front bumper of the vehicle first contacted the barrier face 49.2 feet (15 m) from the upstream end of the barrier. The measured impact speed was 56.2 mph (90.4 km/hr), at an impact angle of 25 degrees. The left front tire initially contacted the lower part of the CMB 50.3 feet from the upstream end. The highest mark on the barrier was 32 inches (0.8 m). The body contact with the CMB extended for a length of 12.5 feet (3.8 m) starting 49.3 feet (15 m) from the upstream end of the barrier. The length of the body contact with the CGS began 50.8 feet (15.5 m) from the upstream end of the barrier.

The test vehicle was smoothly redirected without exhibiting any tendency to snag or pocket with an exit angle of 5 degrees. It remained upright throughout and after collision. The exit velocity was 56.2 mph (90.5 km/hr). Exit velocity and angle are measured at the time after impact when the vehicle loses contact with the barrier.

During redirection, the test vehicle experienced a maximum positive roll of 18 degrees and a positive pitch of 5 degrees (see sign convention figure in Appendix C.) The remote brakes were applied after the vehicle lost contact with the barrier and the vehicle went off the paved area. It came to rest 118 feet (36 m) downstream from the end of the CGS and 60 feet (18.3 m) behind it.

The maximum 50 millisecond average accelerations were -6.6g's in the longitudinal direction and -10.0 g's in the lateral direction. The values of occupant impact velocity were 21.2 fps in the lateral direction and 21.9 fps in the longitudinal direction. The ridedown accelerations were -16.3 g's laterally and -5.5 g's longitudinally.

Figure 9: Data Summary Sheet for Test 482



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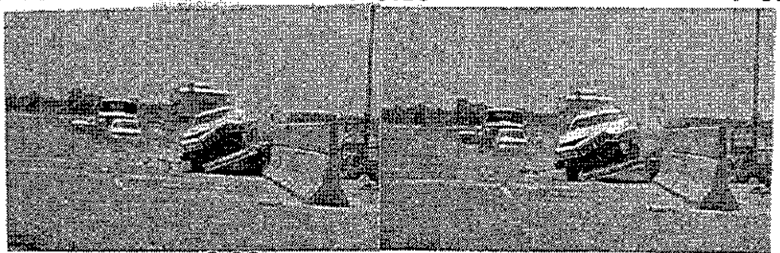
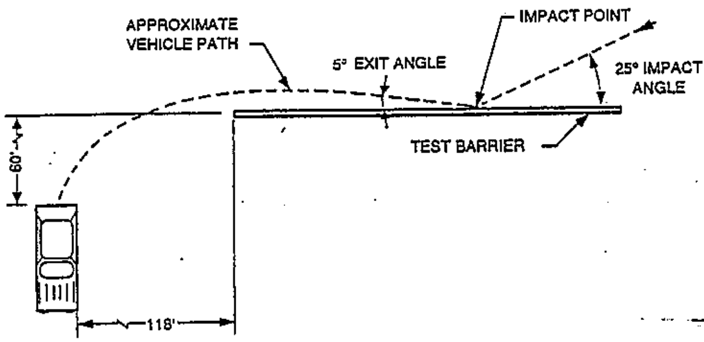
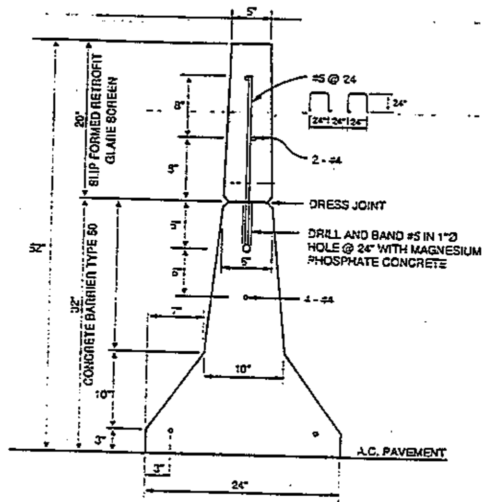


t=0.30 t=0.40





Test Barrier:

Type:	50R Concrete Glare Screen Slipformed on top of California Concrete Median Barrier - Type 50
Length:	150 feet

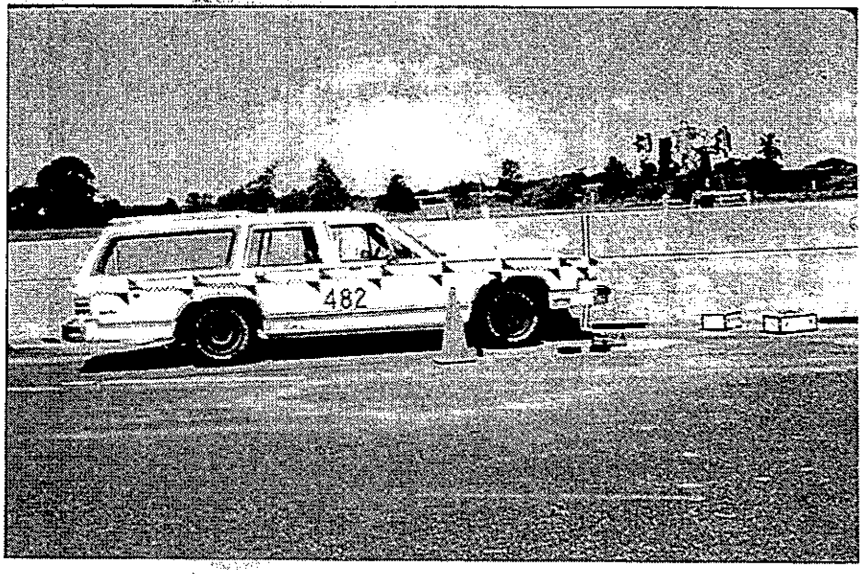
Test Date: 5/2/90

Test Vehicle:

Model:	1982 Mercury Station Wagon
Inertial Mass:	4360 lb
Impact Velocity:	56.2 mph
Impact/Exit Angle:	25°/5°

Test Data:

Occupant Impact Velocity:	21.2 fps long. / 21.9 fps lat.
Ridedown Acceleration:	-5.5 g's long. / -16.3 g's lat.
Max. 50 ms Avg. Accel.:	-6.6 g's long. / -10 g's lat.
TAD/VDI:	11LFMW5/LFQ-5
Max. Roll, Pitch & Yaw:	18°/5°/0°
Barrier Displacement:	0 inch
Max. Dynamic Deflection:	0.21 inch
Barrier Damage:	Few hair-like cracks, scrapes and tire marks.



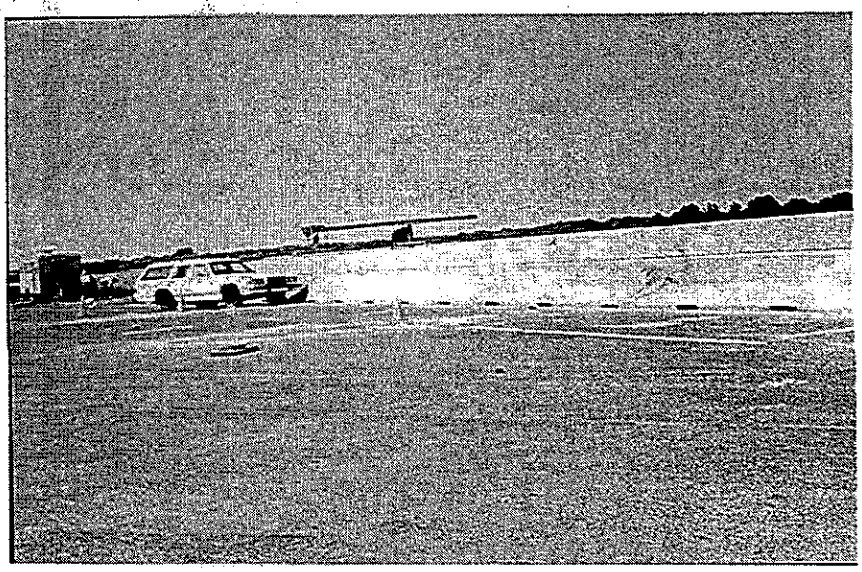


Figure 10: Pre-Impact Photos, Test 482

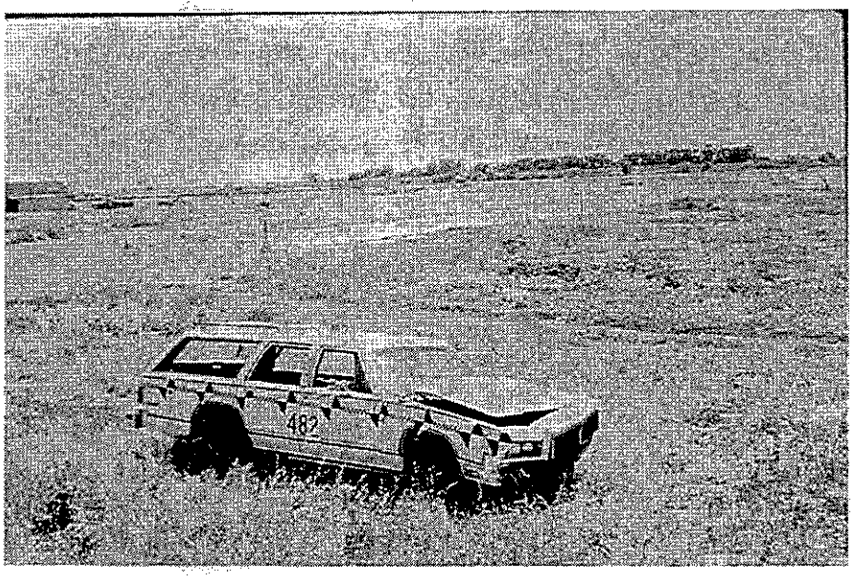


Figure 11: Post-Impact Photos, Test 482

5.2.2.2 Vehicle Damage - 482

The test vehicle was severely damaged. The sheet metal on the left side of the body was crushed and the front bumper was disconnected from the car. The contact pattern initiated at the left corner of the front bumper resulted in the left shock bolts (bolts attaching shock absorber to body) being completely sheared off during the impact. Consequently, the entire bumper was torn off and thrown 21 feet (6.4 m) away from the barrier face and 35 feet (10.7 m) from the downstream end of barrier. The grill frame was crushed at its left side and cracked at its right. The radiator was pushed back to the fan. The hood was closed and could not be opened; one of the hood hinges was broken. The whole front part of the car was moved toward the right. The first target on the hood was displaced 7.5 inches (0.2 m) as compared to the car centerline. The left door was scraped, jammed and could not be opened. The left front fender was severely scraped and crinkled, and moved back about two inches (0.1 m). The left rear door was scraped; the left door post was torn almost loose at the roof. The right front fender was crinkled and broken. The right door was jammed. The roof over the door posts was crimped. The left front tire was flat and torn. All wheels had restricted movement due to front and rear axle failure.

Vehicle debris covered an area 135 feet (41.2 m) long starting at the impact point and 24 feet (7.3 m) wide, 21 feet (6.4 m) in front of the barrier and three feet (0.9 m) behind it. There was no intrusion of vehicle or barrier parts into the passenger compartment during impact.

5.2.2.3 Barrier Damage

There was no evidence of any structural distress of the CGS or CMB. The only damage imparted to the barrier was minor extension of a few preexistent hair line cracks. About eight hair like cracks one to four and a half inches long developed on the top face of the CGS over a length of 3.5 feet upstream from the 60-foot mark. A preexisting crack root on the barrier face at about 60 feet from barrier upstream end went on for an additional one and a half inches. Two preexisting contraction cracks on the back of the barrier branched out five hair like cracks three to four inches long. These preexisting cracks were located at 0.4 and 6.4 feet downstream from the 60-foot mark.

The length of gouges from the vehicle on the CGS was 10 ft and about 12.5 ft on the CMB. The tire marks covered a length of 10 1/2 feet on the CMB. An oil spill on the barrier face covered a length of about nine feet starting at 4.7 feet downstream from the 50-foot mark.

The maximum dynamic lateral displacement was 0.21 inches (5.3 mm) measured 1/2 inch from the top, and there was no permanent deflection.

5.3 DISCUSSION OF TEST RESULTS

5.3.1 General - Safety Evaluation Guidelines - NCHRP Report 230

Three evaluation factors were used in judging the impact test performance of the test barrier, as recommended by NCHRP Report 230 (6). These factors are: (1) structural adequacy. (2) occupant risk, and (3) vehicle trajectory. Tests 481 and 482 were performed to verify the structural adequacy of the CGS. The occupant risk and vehicle trajectory requirements were satisfied in other N.J. shape barrier tests. Nevertheless, they were analyzed in these tests for comparison with past tests.

5.3.2 Structural Adequacy

The structural adequacy was evaluated by comparison of test results with the following criteria from Table 6 of NCHRP Report 230 (6).

"A. Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation, although controlled lateral deflection of the test article is acceptable.

D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic."

These criteria were met completely in both Test 481 and 482. The CMB/CGS demonstrated its ability to retain and redirect the test vehicles under different impact conditions. Vehicle redirection was very smooth in both tests. The vehicles were adequately redirected without penetration, and the overall adequacy of the barrier and the concrete glare screen were demonstrated. In these tests there was no evidence of any structural distress of the barrier; however, there were some minor surface cracks. No pieces of the barrier were broken, and no portions of the barrier showed potential for penetrating the passenger compartment. Both Test 481 and 482 were performed on the same barrier with impact points 50 ft apart. Lateral movement of the CGS was measured during the test; dynamic deflection was up to 0.2 inches, but there was no permanent deflection.

5.3.3 Occupant Risk

The occupant risk was evaluated by comparison of test results with the following criterion from Table 6 of NCHRP Report 230 (6).

> "E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion."

Table 2 shows maximum roll, airborne distance, and maximum 50ms average accelerations for both test 481 and 482. Included in the table, for comparison, are similar data from previous tests on concrete safety shape barriers tested by Caltrans. Note that the magnitude of roll in test 481 and 482 is generally lower than in some other tests of concrete safety shape barriers. In both tests the amount of roll and pitch may be considered low to moderate. Neither of the two test cars showed any indication of being close to rollover. There was no deformation or intrusion into the passenger compartment.

The values of longitudinal occupant impact velocity in Test 481 and 482 were lower than the NCHRP recommended maximum value and also lower than in some other Caltrans tests on concrete median barriers. Limiting values of occupant impact velocity are given in Criterion F; however, they apply only to lightweight car tests. Nevertheless, the values were calculated and are reported here for comparison with those in similar tests.

The second part of Criterion F in NCHRP Report No. 230 calls for a highest 10ms. average value of longitudinal and lateral vehicle acceleration of 15 g's after the theoretical occupant/compartment impact occurs. In both tests, (481 and 482), these values were less than 15 g's for a 10 ms duration as determined by inspection of the acceleration vs time plot (Appendix C).

Values of occupant impact velocity were not reported for the previous Caltrans tests on CMB because they were conducted before 1981 when NCHRP Report 230 was first published. Occupant Impact Velocities were introduced for the first time in that report. The maximum 50 ms average value of acceleration is a comparable measurement and was reported for all previous Caltrans CMB tests. These values for the CMB/CGS in tests 481 and 482 are generally less than the values for the previous tests with similar test conditions. Hence, it can be concluded that the occupant risk for the CMB/CGS barrier is no worse than that for the Caltrans standard CMB.

Test# / Year	Reference #	Weigt / Speed / Angle	Exit Speed / Angle	Airborne Dist. (ft)	Max. Roll	50 ms Accel Long.	50 ms Accel Lat.
481 / 1990		*5390 / 55.5 / 20.0*	*45.7 / 9*	*0*	*13.1*	*-4.6 g*	*-11.3 g*
482 / 1990		*4360 / 56.2 / 25.0*	*56.2 / 5*	*0*	*18*	*-6.6 g*	*-10 g*
261 / 1972	10	4960 / 61 / 9.5	na / 0	na	na	0.6 g	3.9 g
262 / 1972	10	4960 / 59 / 25.0	57 / na	50	na	7.0 g	11.6 g
264 / 1972	10	4860 / 64 / 25.0	54 / 5	20	na	5.2 g	13.0 g
291 / 1972	11	4860 / 65 / 7.0	54 / 18	na	18	1.2 g	3.4 g
292 / 1972	11	4860 / 68 / 23.0	na / na	56	61	6.8 g	11.8 g
293 / 1973	11	4860 / 66 / 40.0	na / na	60	18	12.8 g	6.5 g
294 / 1974	11	4700 / 39 / 25.0	na / 4	16	33	2.7 g	5.5 g
301 / 1974	12	4860 / 68 / 27.0	50 / 13.8	30	26.5	11.7 g	13.8 g
321 / 1976	13	4700 / 61 / 26	45 / 7	5	48	4.4	9.9

Table 2: Comparison of CGS Tests 481 and 482 to Concrete Safety Shape Barriers Tested By Caltrans

It should be noted that none of the above means of evaluating the occupant risk are exact methods of predicting injury levels during impacts. NCHRP Report 230 states that "Whereas the highway engineer is ultimately concerned with safety of the vehicle occupants, the occupant risk criteria should be considered as the guidelines for generally acceptable dynamic performance. These criteria are not valid, however, for use in predicting occupant injury in real or hypothetical accidents". The explanation is given that "relationship between vehicle dynamics and probability of occupant injury and degree of injury sustained is tenuous, because it involves such important but widely varying factors as occupant physiology, size, seating position, restraint, and vehicle interior geometry and padding". However, low occupant impact velocity and ridedown acceleration values indicate relatively safe roadside safety features.

5.3.4 Vehicle Trajectory

The vehicle trajectory was evaluated by comparison of test results with the following criteria from Table 6 of NCHRP Report 230 (6):

"H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.

I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60% of test impact angle, both measured at time of vehicle loss of contact with test device."

The same report stresses that "trajectory evaluation for redirectional type of tests is focused on the vehicle at the time it loses contact with the test article, and the subsequent part of the trajectory is not evaluated". The exit angles for both tests did not exceed the recommended upper limit of 60 percent of the impact angle (6).

The vehicle speed change was less than the 15 mph (24.2 km/h) limit for both tests (481 and 482). These low changes in vehicle speed correspond to the relatively low values of longitudinal vehicle acceleration.

Regardless of speed change and exit angles, the barrier demonstrated its ability to retain a vehicle under very severe impact conditions. There was no tendency to pocket or snag the vehicle.

The vehicle post impact trajectories followed the same patterns in both tests (481 and 482). The vehicles were redirected toward the line of the barrier. Following the barrier impact, both vehicles rebounded from the barrier in a disabled condition and traveled 118 to 135 feet before coming to a stop. The final positions were across the line of the barrier. If the barrier had extended further downstream, the vehicle would have impacted it a second time in both tests. The differences in vehicle trajectory may be attributed to variations in the timing of brake application and vehicle characteristics, such as weight distribution, suspension system, tires, vehicle stability after impact, and vehicle damage.

For both tests, the post impact trajectory was as expected for a longitudinal concrete median barrier with or without concrete glare screen. NCHRP Report No. 230 (6) points out, "the after collision trajectory may be one of the least repeatable performance factors" and there is no assurance that existing hardware or certain classes of appurtenances will perform within NCHRP Report 230 limits for exit angle and speed.

In summary the CMB/CGS did meet the vehicle trajectory requirements of NCHRP Report 230 (6).

5.3.5 Concrete Median Barriers - Standard Design in California

Concrete safety shape barriers were approved for use in narrow medians in California in 1971. This barrier has long been the standard for new installations and for replacement of older types. Approximately one-half of the total median barrier inventory in California is concrete barrier (8). The Type 50 Concrete Median Barrier has the highest percentage of unreported accidents since, in flat angle collisions with this barrier, most vehicles are redirected by the safety shape with no damage and can be driven away. This is also the cleanest barrier, with no projections to collect debris (2). Comparison of test results from Tests 481 and 482 with test results from the standard Caltrans CMB design show that the new CMB/CGS design when added to the Type 50 CMB, does not degrade the crashworthiness of the Type 50 CMB. There does not appear to be any degradation in crashworthiness due to the addition of a CGS to the standard CMB.

5.3.6 Glare Screen Design

No major changes were made to the CGS design after construction and testing. The cross-sections showed a homogeneous, well consolidated concrete mixture with no air pockets. In addition, the x-ray tests showed no considerable change in the location of the rebars during the slipforming operation. The x-rays also showed a uniform concrete density with good contact between the concrete and the rebars. The only change made to the plans was modifying the design to use vertical rebars instead of wickets. This provides for better consolidation of the concrete without altering the strength of the barrier considerably.

1. "Standard Plans", California Department of Transportation, Sacramento, CA, January 1988.

2. "Traffic Manual", California Department of Transportation, Sacramento, CA, January 1987.

3. Interoffice Memo from E.D. Spartz, Chief, Caltrans Value Engineering and Resource Conservation Branch to Jack Cropper, Chief, Caltrans Division of Highway Maintenance dated December 4, 1986, transmitting Final Report of "Value Engineering Study of Glare Screen in High-Maintenance Areas".

4. "Glare Screen Guidelines", National Cooperative Highway Research Program Synthesis of Highway Practice 66, December 1979.

5. Arnold, C.J. and Chiunti, M.A., "Construction and Impact Testing of a Short Section of Experimental Concrete Glare Screen", Michigan Dept. of State Highways Research Report No. R-879, August 1973.

6. "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances", Transportation Research Board, National Cooperative Highway Research Program Report 230, March 1981.

7. "Standard Specifications", California Department of Transportation, Sacramento, CA, 1989.

8. Seamons, L.L. and Smith, R.N., "Past and Current Median Barrier Practice in California", California Department of Transportation, June 1991.

9. "Manual of Inspection", California Department of Transportation, Sacramento, CA, 1989

10. Nordlin, E.F., et al, "Dynamic Tests of Prestressed Concrete Median Barrier Type 50, Series XXVI", Report No. CA-HY-MR-6588-1-73-06, California Division of Highways, March 1973.

11. Nordlin, E.F., et al, "Dynamic Tests of a Prestressed Concrete Median Barrier Type 50, Series XXVI", California Division of Highways, March 1973.

12. Parks, D.M., et al, "Vehicular Crash Tests of Unanchored Safety-Shaped Precast Concrete Median Barriers With Pinned End Connections", California Department of Transportation, August 1976.

13. Nordlin, E.F., et al, "Dynamic Test of a Slipformed Concrete Barrier Type 50 Placed Over Lowered Existing Cable Barrier", Report No. CA-DOT-TL-6696-1-74-36, California Department of Transportation, December 1974.

14. Parks, D.M., et at, "Vehicular Crash Test of a Continuous Concrete Median Barrier Without a Footing", California Department of Transportation, August 1977.

Test Vehicle Equipment and Cable Guidance System

The test vehicles were modified as follows for the crash tests:

* The gas tanks on the test vehicles were disconnected from the fuel supply line and drained. Shortly before the test, dry ice was placed in the tanks of the test vehicles as a safety precaution to drive out the gas fumes. A one-gallon (3.78 L) safety gas tank was installed in the vehicles and connected to the fuel supply line.

* Six 12-volt wet cell motorcycle storage batteries were mounted in the vehicle. Two supplied power to a high-speed camera and lamps located inside the vehicle. Another pair of batteries operated the solenoid-valve braking system and other test equipment in the vehicle. The third pair of batteries powered the PACDAS data acquisition system.

* The gas pedal was linked to a small cylinder with a piston which opened the throttle. The piston was started by a hand thrown switch on the rear fender of the test vehicle. The piston was connected to the same CO_2 tube used for the brake system, but a separate regulator controlled the pressure.

* A speed control device connected between the negative side of the coil and the vehicle battery regulated the speed of the test vehicle based on speedometer cable output. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tape switches set a known distance apart and connected to a digital timer.

* A cable guidance system directed the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path to a threaded coupler embedded in a concrete footing, passed through a guide bracket bolted to the spindle of the front wheel of the vehicle. A steel knockoff bracket, anchoring the end of the cable closest to the barrier to a concrete footing, projected high enough to knock off the guide bracket, thereby releasing the vehicle from the guidance cable before impact.

A microswitch was mounted below the front bumper and connected to the ignition system. A trip plate on the ground near impact triggered the switch when the car passed over it, thus opening the ignition circuit and cutting the vehicle engine before impact.

* A solenoid-valve actuated CO_2 system controlled remote braking after impact or emergency braking any other time. Part of this system was a cylinder with a piston which was attached to the brake pedal. The pressure operating the piston was set during trial runs to stop the test vehicle without locking the wheels. When activated, the brakes were applied in less than 100 milliseconds.

* The remote brakes were controlled at the console trailer. A cable ran from the console trailer to the electronic instrumentation trailer. From there, the remote brake signal was carried on one channel of the tether line which was connected to the test vehicle. Any loss of continuity in these cables activated the brakes and cut off the ignition automatically. Also, when the brakes were applied by remote control from the console trailer, the ignition was automatically cut off.

Figures A1 and A2 on the following pages show the vehicle dimensions. Dimensions were measured.

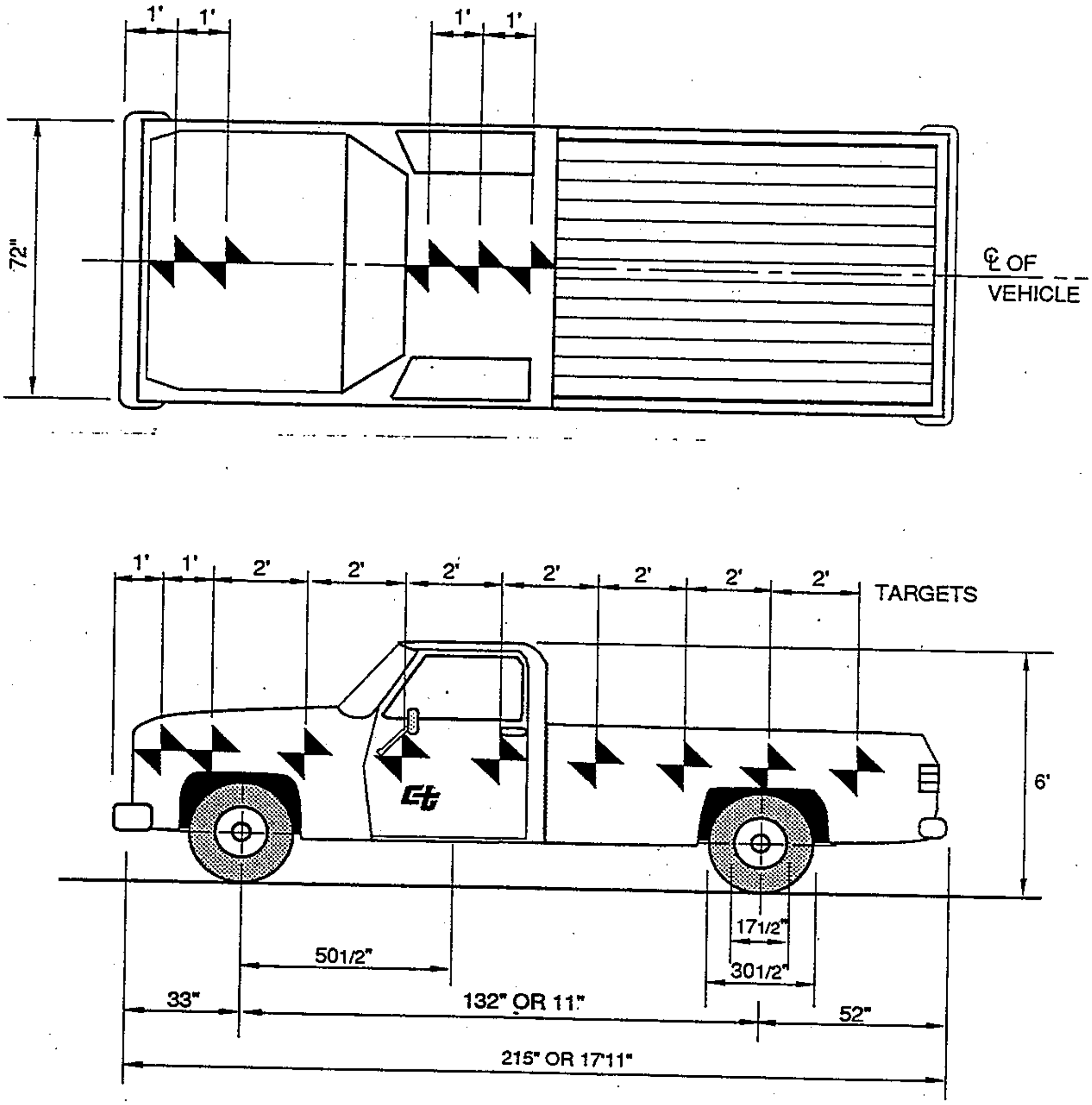


Figure A1: Vehicle Dimensions, Test 481

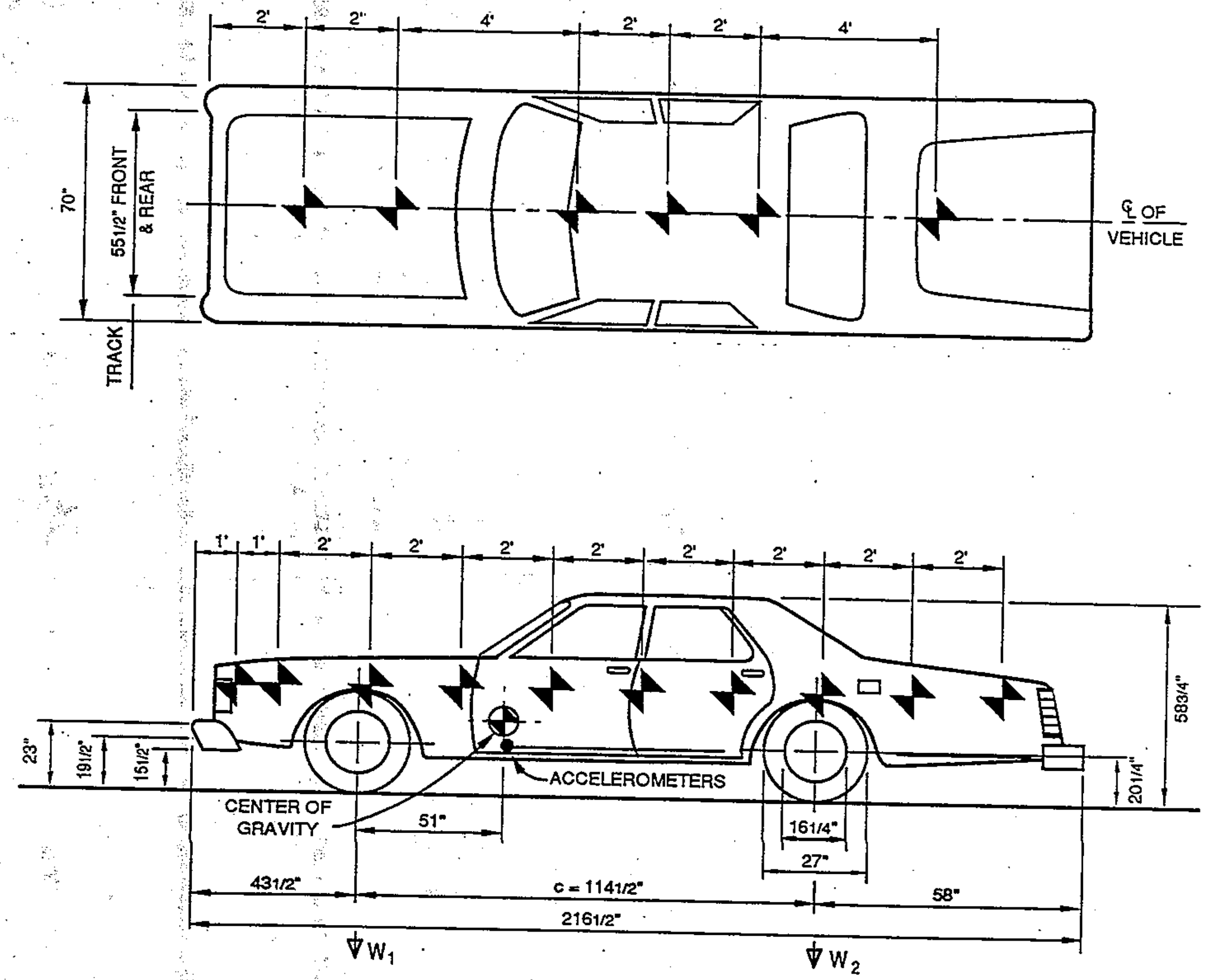


Figure A2: Vehicle Dimensions, Test 482

PHOTO - INSTRUMENTATION

Several high-speed movie cameras recorded the impact during the crash test. The types of cameras and their locations are shown in Figure B1.

All of these cameras were mounted on tripods except three cameras that were mounted on a 35-foot (10.7 m) high tower directly over the point of impact on the test barrier.

These cameras were connected by cables to a console trailer near the impact area which contained eight 12-volt batteries. Most of the cameras were turned on remotely from a control panel on the trailer. The test vehicle and test barrier were photographed before and after impact with a normal speed movie camera, a black and white still camera and a color slide camera. A film report of this project has been assembled using edited portions of the movie coverage.

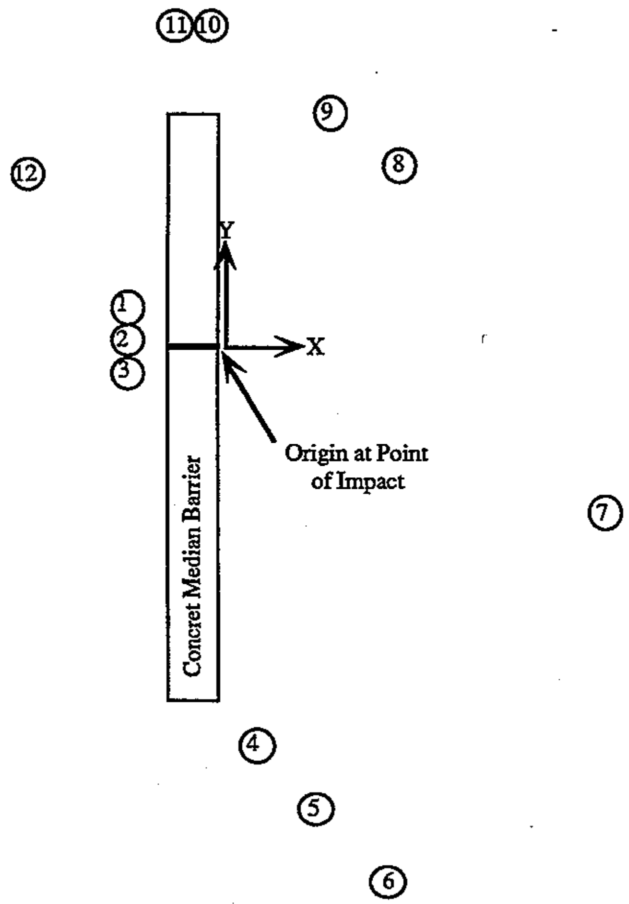
Following are the pretest procedures that were required to enable film data reduction on a Vanguard Motion Analyzer:

* Butterfly targets were attached to the top and sides of the test vehicles. The target locations are shown in Figures A1 and A2. The targets established scale factors and horizontal and vertical alignment. The test barrier was targeted with black and white tape also.

* Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle to barrier contact, and (b) the application of the vehicle brakes. The impact flashbulbs have a delay of several milliseconds before lighting up.

* Five tape switches, placed at 10-foot (3.05 m) intervals, were attached to the ground perpendicular to the path of the impacting vehicle near the barrier. Flash bulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of most of the data cameras. The flashing bulbs were used to correlate the cameras with the impact events; and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure B2. All high-speed cameras had timing light generators which

exposed red timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships.



Cam. No.	Film mm	Camera		Coordinates, ft.			
			Rate:	Test 481		Test 482	
		Type	Frames/s.	X	Y	X	Y
1	16	PHOTOSONICS	400	NA	1.5	NA	1.5
2	16	REDLAKE - LOCAM	400	NA	NA	NA	NA
3	16	PHOTOSONICS	400	NA	-1.5	NA	-1.5
4	16	PHOTEC	400	1.5	-106.8	NA	-118.0
5	16	REDLAKE - LOCAM	400	NA	NA	NA	-132.0
6	16	REDLAKE - LOCAM	400	NA	NA	NA	NA
7	16	REDLAKE - LOCAM	400	118.5	NA	114.0	-108.0
8	16	REDLAKE - LOCAM	400	82.3	27.2	88.0	NA
9	16	REDLAKE - LOCAM	400	55.0	49.2	68.0	42.0
10	16	REDLAKE - LOCAM	400	NA	261.2	NA	178.0
11	35	HULCHER 35	20	NA	261.2	NA	178.0
12	16	REDLAKE - LOCAM	400	-59.0	29.2	NA	NA

Figure B1: Camera Layout

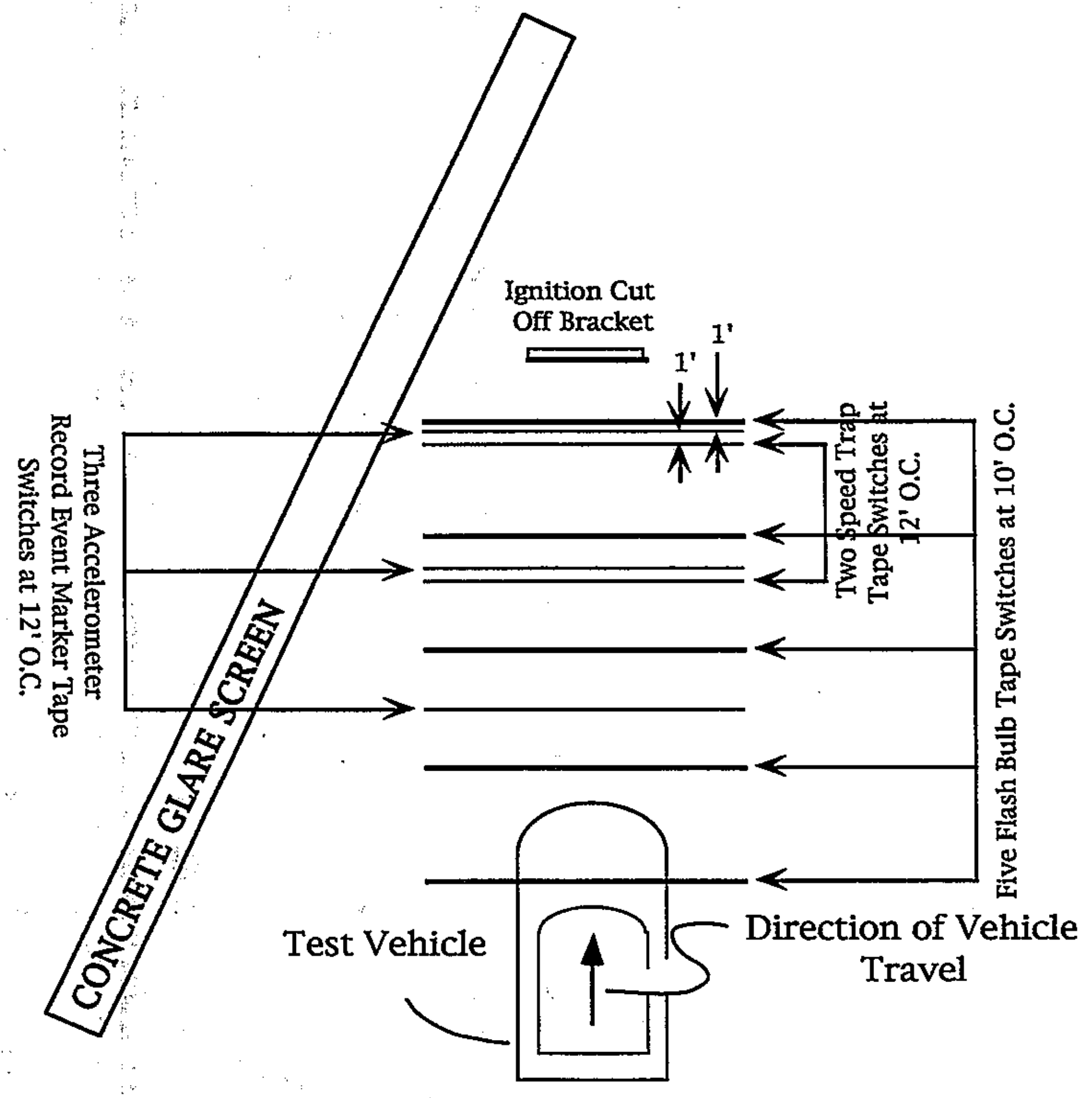


Figure B2: Tape Switch Layout

Electronic Instrumentation and Data

Three unbonded strain gage accelerometers (Statham) measured acceleration in the longitudinal, lateral and vertical directions. They were near the longitudinal and lateral center of gravity of the vehicles. These accelerometers were mounted on a small rectangular steel plate which was bolted to another steel bracket that was welded to the floorboard. Figures A1 and A2 show the location of these accelerometers. Table C1 gives information on the accelerometers used. Figure C1 shows the sign conventions for the vehicle accelerometers.

TYPE	LOCATION	RANGE	ORIENTATION
STRATHAM	VEHICLE C.G.	100 G	LONGITUDINAL
STRATHAM	VEHICLE C.G.	100 G	LATERAL
STRATHAM	VEHICLE C.G.	50 G	VERTICAL
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	ROLL
HUMPHREY	VEHICLE C.G.	90 DEG/SEC	PITCH
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	YAW

Table C1: Accelerometer And Rate Gyro Data

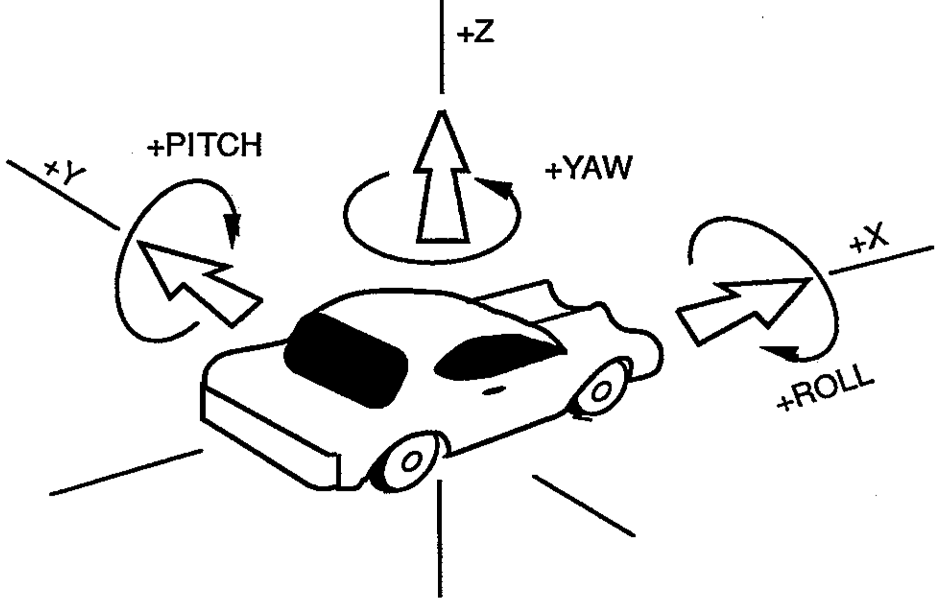


Figure C1: Vehicle Acceleration Sign Convention

Data from the accelerometers in the test vehicle were transmitted through a 1000-foot (304.8m) Belden number 8776 umbilical cable connecting the vehicle to a 14 channel Hewlett Packard 3924C magnetic tape recording system. This recording system was in an instrumentation trailer at the test control area. The accelerometer data were also recorded on a Pacific Instruments digital data recorder (PACDAS) which was mounted in the vehicle. The PACDAS data were reduced using a microcomputer.

Three pressure-activated tape switches were placed on the ground in front of the test barrier. They were spaced at carefully measured intervals of 12 feet (3.7 m). When the test vehicle tires passed over them, the switches produced sequential impulses or "event blips" which were recorded concurrently with the accelerometer signals on the tape recorder and served as "event markers". These signals were also transmitted back to the PACDAS through the umbilical cable. A tape switch on the front bumper of the vehicle closed at the instant of impact and activated flash bulbs mounted on the vehicle. The closure of the bumper switch also put a "blip" or "event marker" on the recording tape and PACDAS. A time cycle was recorded continuously on the tape and PACDAS with a frequency of 500 cycles per second. The impact velocity of the vehicle could be determined from the tape switch impulses and timing cycles. Two other tape switches connected to digital readout equipment were placed 12 feet (3.7 m) apart just upstream from the test barrier specifically to determine the impact speed of the test vehicle immediately after the test was completed. The tape switch layouts are shown in Appendix B in Figure B2.

The data curves are shown in Figures C2 through C8 and include the accelerometer and rate gyro records from the vehicle for Tests 481 and 482. They also show the longitudinal velocity and displacement vs. time. These plots were needed to calculate the occupant impact velocity defined in Reference 6. All curves were calculated using the PACDAS.

The occupant impact velocity is theoretical; however, on the plot of distance vs. time, the curves can be visualized as representing the car windshield and the driver's head. It is assumed that the head starts out two feet (0.6m) behind the windshield. The point where the curves cross represents the impact between the head and the windshield because the windshield has slowed down from the impact velocity, but the head has not. The time when the windshield/head impact occurs (rattle space time) is carried to the plot of velocity vs. time. The occupant impact velocity is the difference between the vehicle impact velocity and the vehicle velocity at the end of the rattle space time.

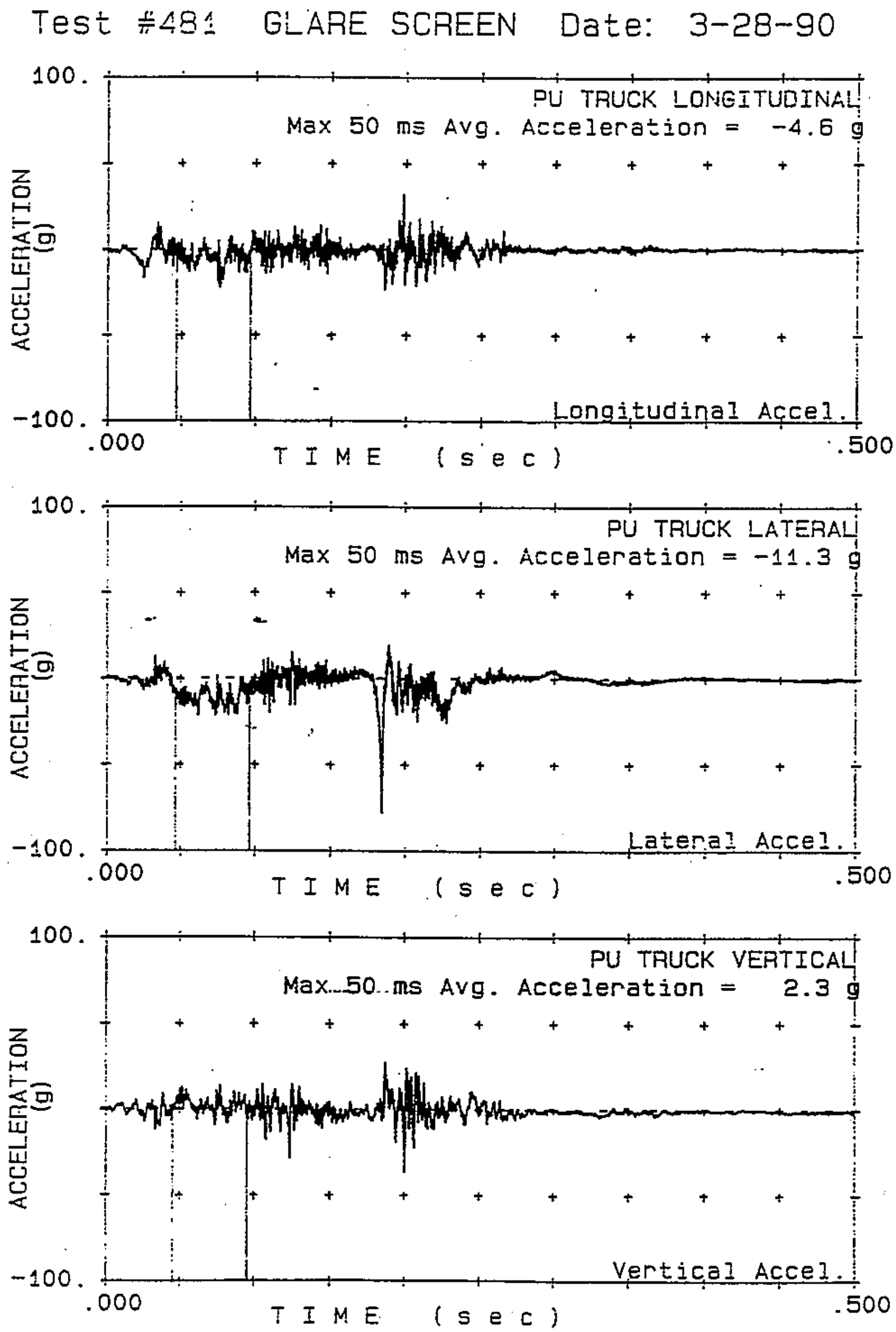


Figure C2: Test 481 - Vehicle Accelerations

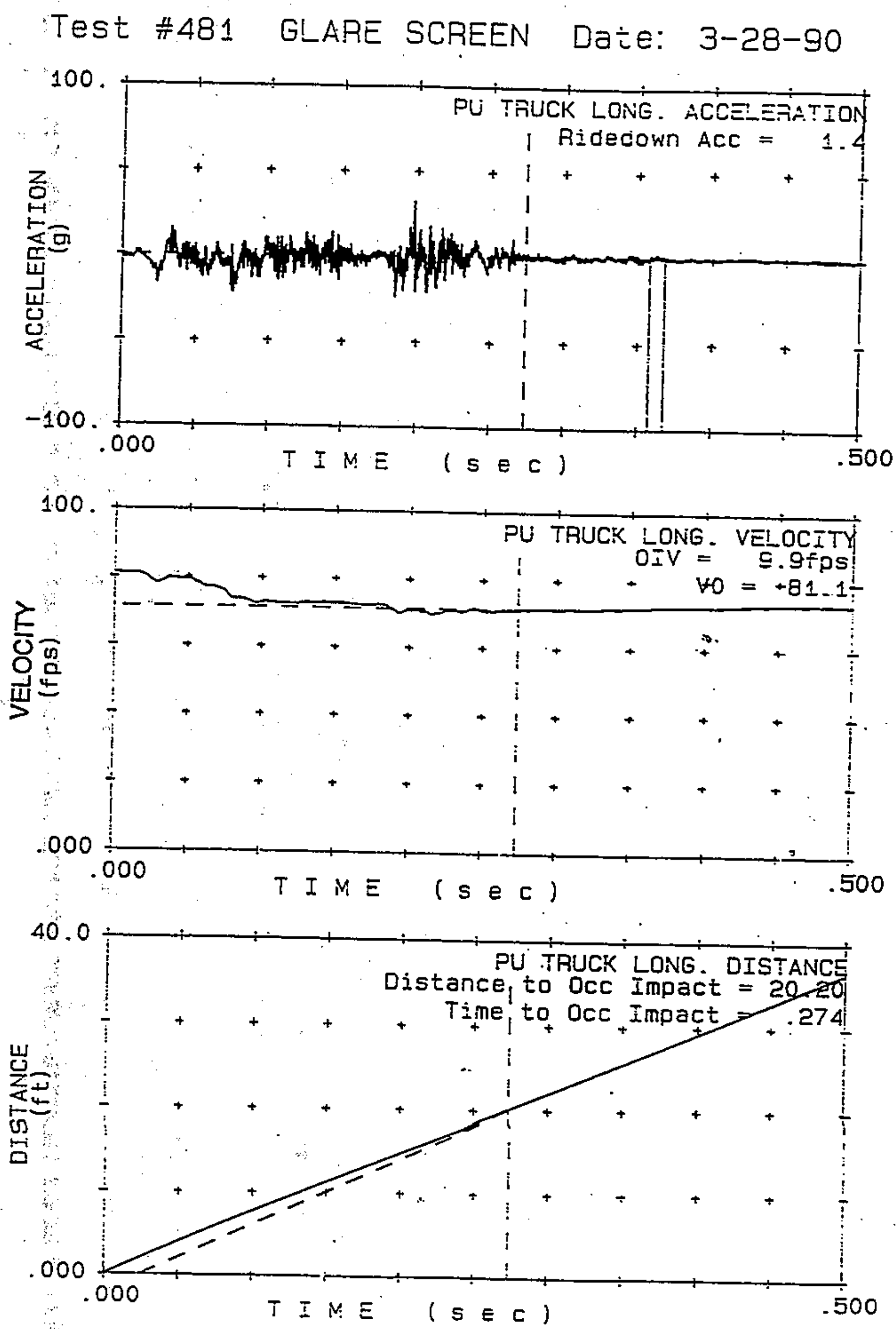


Figure C3: Test 481 - Vehicle Accelerations

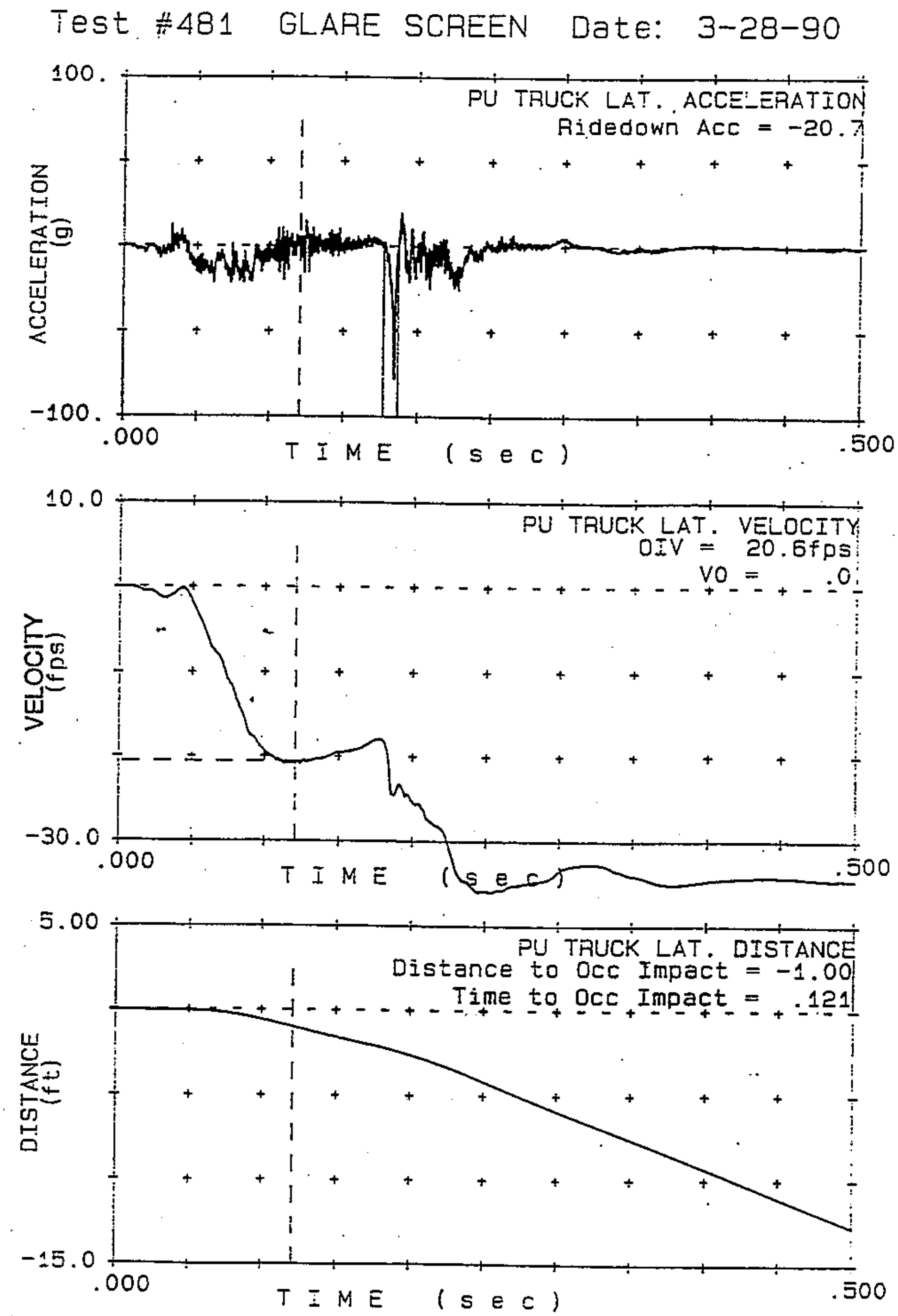


Figure C4: Test 481 - Vehicle Accelerations

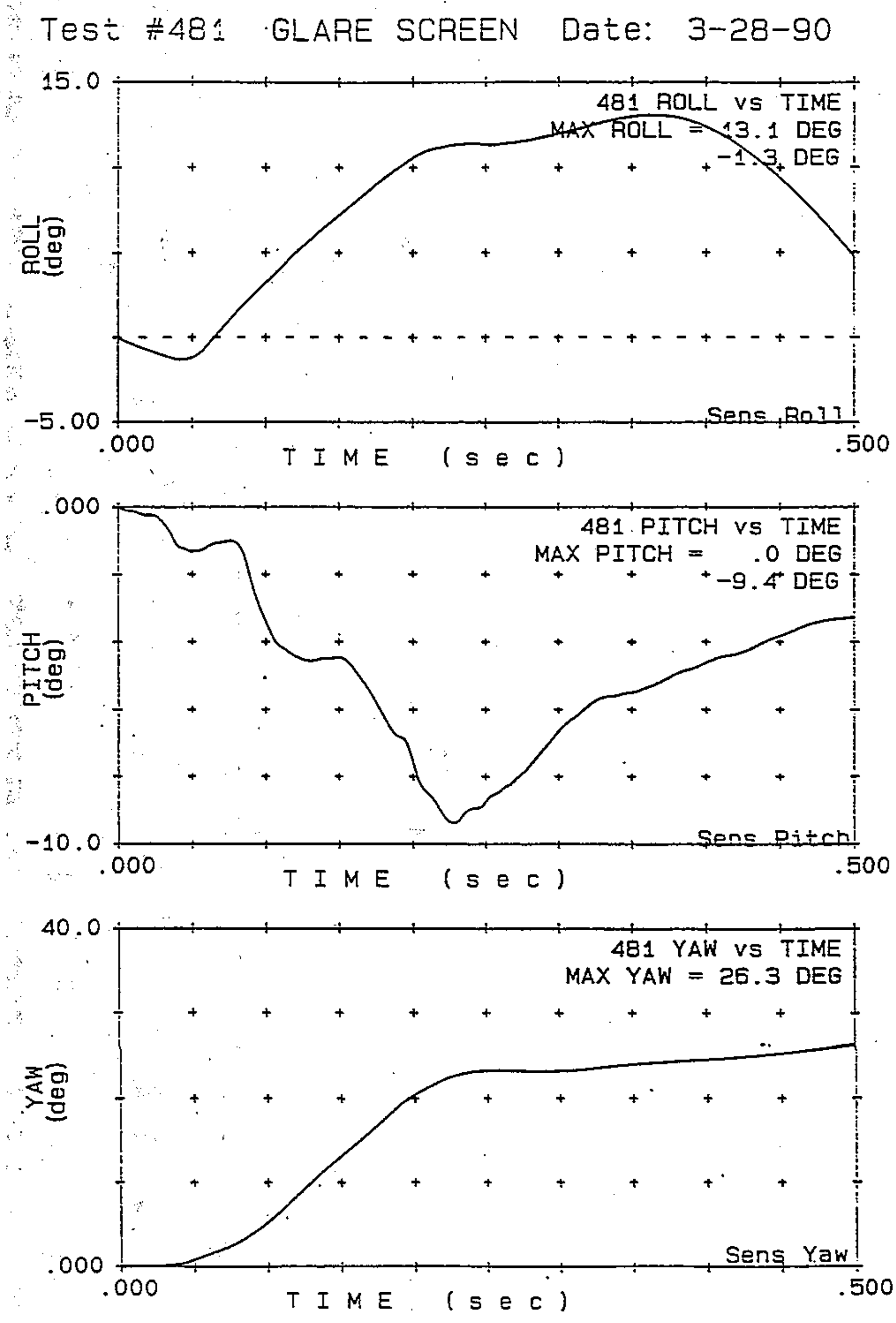


Figure C5: Test 481 - Vehicle Accelerations

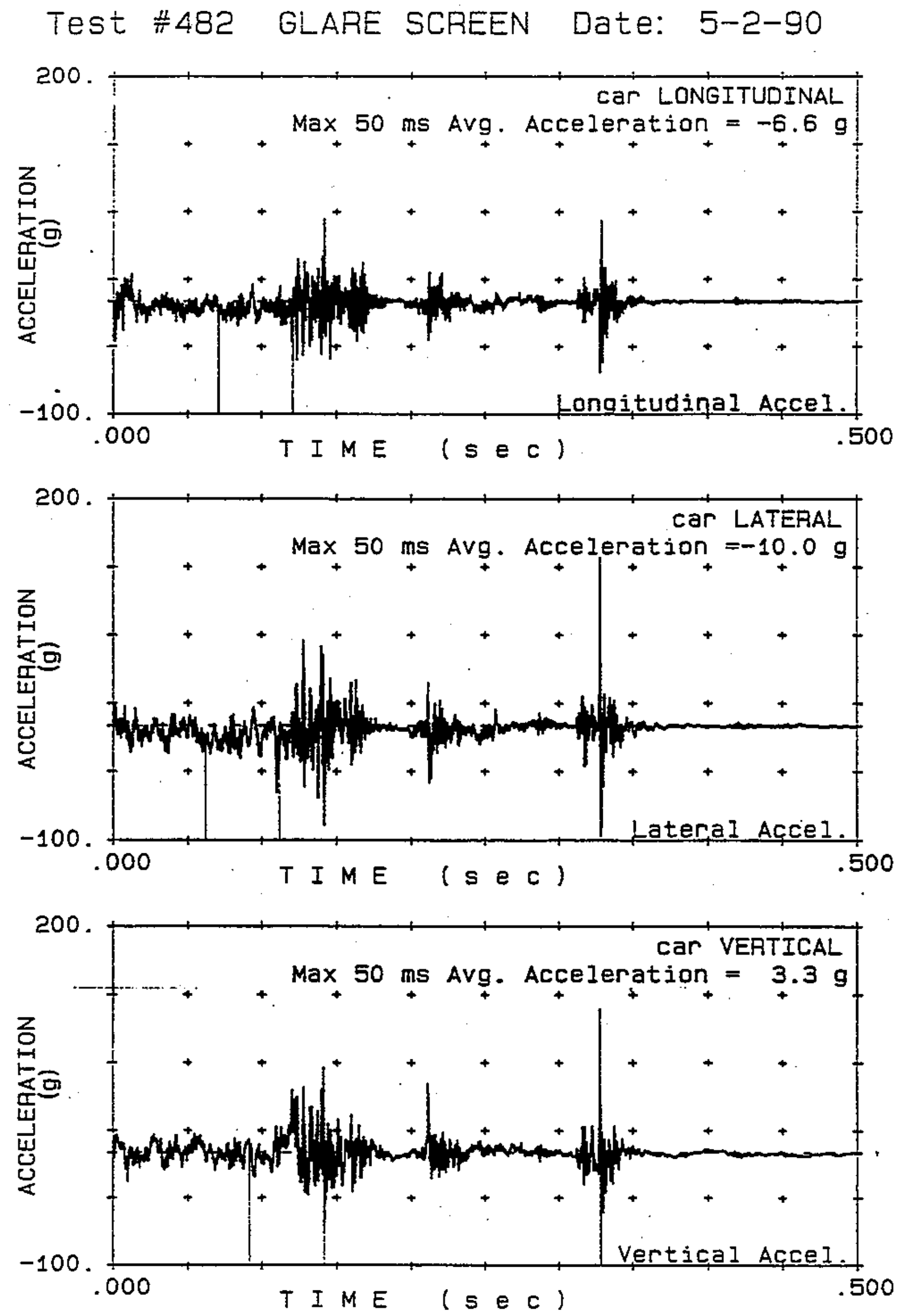


Figure C6: Test 482 - Vehicle Accelerations

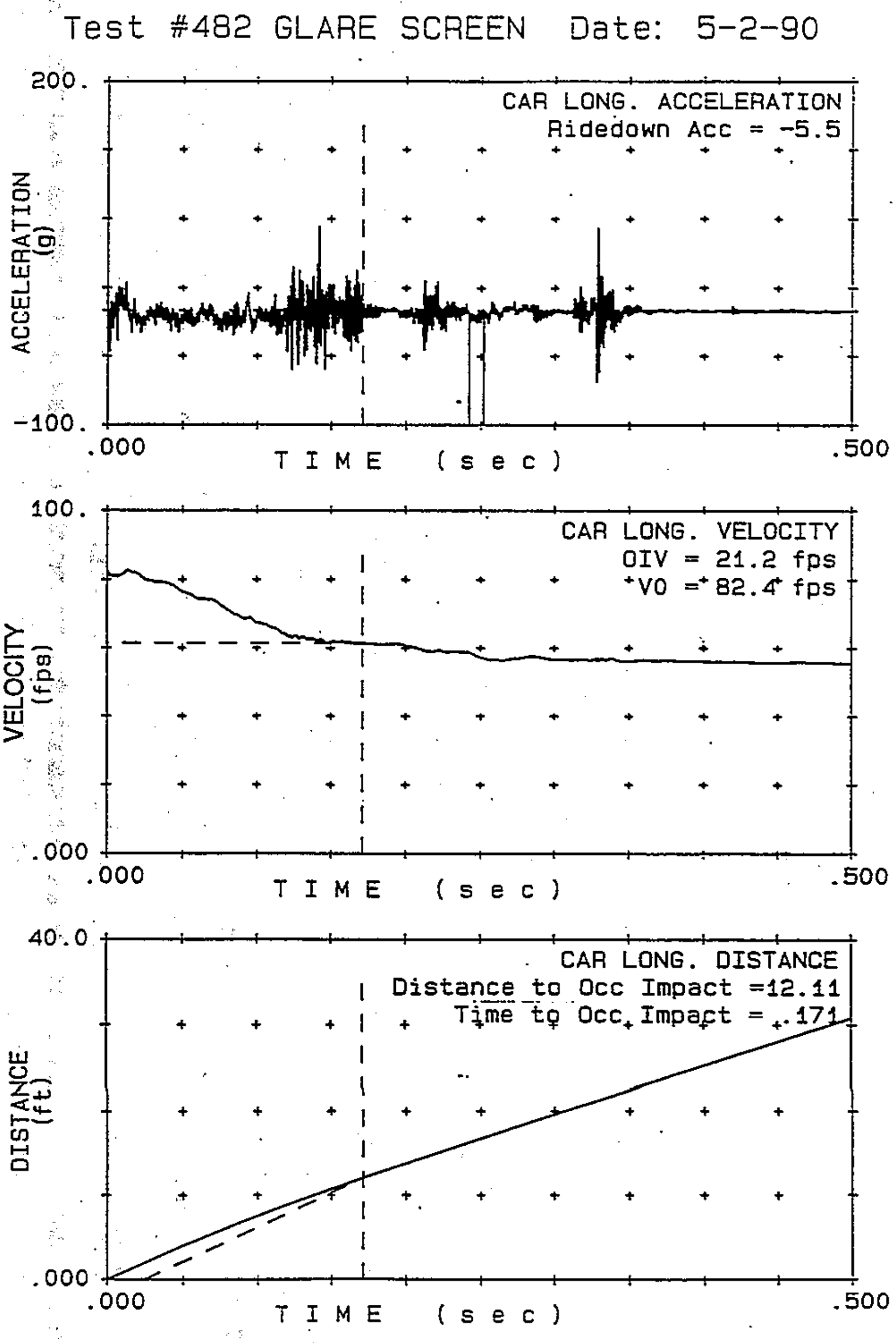


Figure C7: Test 482 - Vehicle Accelerations

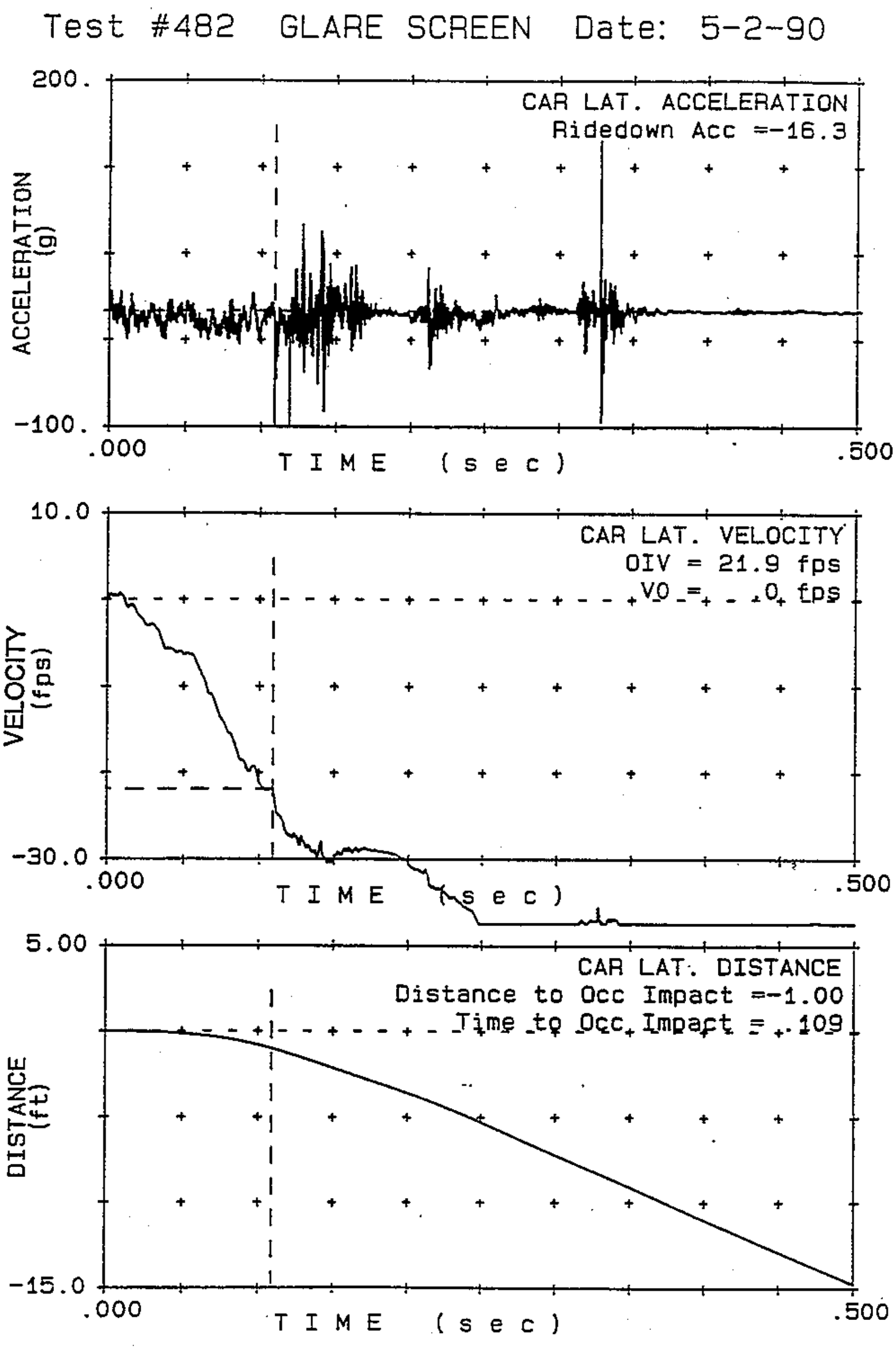


Figure C8: Test 482 - Vehicle Accelerations

The vehicle accelerometers were used in determining the occupant impact velocity.

Rate gyros were mounted next to the vehicle accelerometers. They measured the rate of angular change (angular velocity) of the vehicle in the roll, pitch, and yaw directions. Table C1 give information on the rate gyros used. Figure C1 shows the sign convention for the rate gyros. The data from these transducers were transmitted on the same umbilical cable as the vehicle accelerometers and were also recorded on PACDAS. The rate gyro data were integrated to obtain a curve of angle position versus time after impact so the maximum value of roll, pitch and yaw could be determined.

Test Barrier Materials Tests

Both the rebar and the concrete that were used in the construction of the CMB and CGS were tested for compliance with ASTM and Caltrans specifications. The rebar was tested in accordance with ASTM A615-60 which it passed. Static strength tests were performed on concrete samples from the CGS and the results are the following:

Sample Age (Days)	Static Strength (psi)
5	2960
7	3440
14	3870
36	4240

The concrete was 4 to 5 months old when the crash tests were performed.